

# **Dyes and Dyeing Methods in Late Iron Age Finland**

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University of Helsinki

DYES AND  
DYEING METHODS  
IN LATE IRON AGE FINLAND

Krista Vajanto

ACADEMIC DISSERTATION

To be publicly discussed, by due permission of the Faculty of  
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on the 16<sup>th</sup> of January, 2016, at 10 o'clock

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*Betula pendula*, *Potentilla erecta*, *Galium boreale*, *Lycopodium annotinum*, *Isatis tinctoria*,  
*Isatis tinctoria*, *Lasallia pustulata*

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# Abstract

This dissertation is about Late Iron Age (AD 800–1055/1300) woollen, visually colourful textile fragments. The aim is to identify the dyeing methods used in Finland during the Late Iron Age and to find the locally used dyestuffs. This dissertation focuses on the archaeological samples from inhumation burials and shipwrecks, which were analysed with visual analysis and microscopy observation. The reference material includes woollen yarns dyed with Finnish traditionally known dye sources.

The archaeological samples and the dyed references were analysed chromatographically at the Cultural Heritage Agency of the Netherlands (RCE) and at the Royal Institute for Cultural Heritage (KIK-IRPA) in Belgium by HPLC (High performance liquid chromatography) and UHPLC (Ultra High performance liquid chromatography). Mordants were analysed at the Nanomicroscopy Center of Aalto University in Finland by SEM-EDX (Scanning electron microscopy with energy-dispersive X-ray spectroscopy). Experimental archaeology was used to reconstruct the actual dyeing methods of red tannins, lichen orchil and plant mordants as well as to test the sustainability of these dyes and the effect of dyeing methods on wool yarns.

The results suggest that three different dyeing methods were used in Late Iron Age Finland: vat dyeing, mordant dyeing and fermentation of tannins. Red tannins were obtained from tree barks such as alder buckthorn (*Rhamnus frangula*) and roots of common tormentil (*Potentilla erecta*). Red anthraquinones were obtained from local bedstraws (*Galium boreale*, *Galium album* and *Galium verum*). Mordants for dyes were prepared by fermenting clubmosses (*Lycopodium* species) and horsetails (*Equisetum silvaticum* and *Equisetum arvense*). Eagles' fern (*Pteridium aquilinum*), common chickweed (*Stellaria media*) and red sorrel (*Rumex acetosella*) were also used in mordanting. Woad (*Isatis tinctoria*) was used for blue dyeing. Purple was obtained from orchil producing lichens such as rock tripe (*Lasallia pustulata*). Dyer's madder (*Rubia tinctorum*) and the yellow flavonoid dyes such as weld (*Reseda luteola*) were interpreted to indicate textile import.

The Middle Ages offered new meanings for life and textile making, new handicraft methods and new dyestuffs, which ended the local prehistoric dyeing tradition. As a result of new cultural influences, red tannins were no longer used to strengthen yarns for warp-weighted loom nor were the blackish-blue and purple textiles dyed in vats in the Late Iron Age manner. The medieval culture provided a faster textile making process and offered horizontal looms and spinning wheels, the boiling method, alum and new dyestuffs.

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Espoo, November 2015

Krista Vajanto

## List of Papers

This dissertation consists of a synthesis paper and five previously published papers. In the synthesis paper, these five papers are referred to with the numbers I– V.

**Paper I:** Vajanto, K. and van Bommel, M.R. 2014a. Dyed textiles from Late Iron Age Finland. *Fennoscandia Archaeologica* XXXI, 61– 78. The Archaeological Society of Finland, Helsinki.

**Paper II:** Vajanto, K. 2014. Nålbinding in Prehistoric Burials – Reinterpreting Finnish 11<sup>th</sup>–14<sup>th</sup>-century AD Textile Fragments. In A.-K. Salmi, T. Äikäs and J. Ikäheimo (eds.), *Sounds Like Theory: XII Nordic Theoretical Archaeology Group Meeting in Oulu 25.–28.4.2012. Monographs of the Archaeological Society of Finland* 2, 21–33.

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**Paper III:** Vajanto, K. 2014. Finnish shipwreck textiles from the 13<sup>th</sup>– 18<sup>th</sup> centuries AD. In S. Lipkin and K. Vajanto (eds.), *Focus on Archaeological Textiles: Multidisciplinary Approaches. Monographs of the Archaeological Society of Finland* 3, 116–131.

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**Paper IV:** Vajanto, K. 2013. Fibre Analysis of Late Iron Age, Early Modern and Modern Finnish Wools. *Fennoscandia Archaeologica* XXX, 81– 94. The Archaeological Society of Finland, Helsinki.

**Paper V:** Vajanto, K. 2014. Textile standards in experimental archaeology. In S. Lipkin and K. Vajanto (eds.), *Focus on Archaeological Textiles: Multidisciplinary Approaches. Monographs of the Archaeological Society of Finland* 3, 62– 75.

[http://www.sarks.fi/masf/masf\\_3/MASF3\\_05\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_3/MASF3_05_Vajanto.pdf)

## Author's contribution to the papers

**Paper I** was planned, samples selected, and illustrations and tables were created by K. Vajanto, who also made the survey of the Finnish research history and dye traditions. The HPLC and UHPL analyses were performed by Dr M.R. van Bommel. 70% of the discussion was written by K. Vajanto and 30% by M.R. van Bommel.

**Papers II, III, IV and V** were written by K. Vajanto.



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# 1. Introduction

## 1.1. Research questions

This study is about Late Iron Age woollen textile fragments, which are often colourful in the visual assessment. This synthesis section is based on Papers I–V (summaries in Appendix 1). My research sheds light on the prehistoric Finnish dyeing craft, local dye sources and dyeing methods. My dissertation does not attempt to create a synthesis of the geographical distribution of Finnish Iron Age dyestuffs, since there is no textile material from the Late Iron Age settlements. Accordingly, my dissertation sheds light on the dyes and dyeing methods used for the funeral/ festival textiles – the garments used in everyday life might have contained totally different dyes.

The colourants that are frequently found in the finds from Central Europe – Dyers madder (*Rubia tinctorum*), weld (*Reseda luteola*) and Dyer's broom (*Genista tinctoria*) – are absent in the locally made Finnish finds (Paper I). According to Finnish folklore and old dye books, dozens of different plants, some lichens, tree barks and cones were used for dyes. As late as the end of 19<sup>th</sup> century AD dyeing materials were still collected from forests, fields and rocks nearby the villages. The cultivation of dye plants never became important in Finland, unlike in certain areas in Central and Southern Europe, where dye plants were cultivated for trade articles.

Dye analyses performed in 2001 and 2004 by TLC (*Thin layer chromatography*) on the Kaarina Kirkkomäki samples detected reddish colourants that were interpreted as red tannins (Walton 2001a and 2004a; Kirjavainen and Riikonen 2005, 2007a, 2007b). These colourants appeared in UHPLC (*Ultra High Performance Liquid Chromatography*) analysis as unknown reddish and orange colourants from the same textiles (Paper I). These unknown compounds as well as those gained by HPLC (*High Performance Liquid Chromatography*) suggested the use of local plant species.

The common mordant used for dyeing with red anthraquinones and yellow flavonoids is alum ( $KAl(SO_4)_2 \cdot 12H_2O$ ), but it does not appear in the Finnish bedrock. The closest alum mines have been in Öland and in Scania (Skåne) in Sweden, but these were not utilised before the Early Modern period (Cardon 2007, 28–29).

Dye sources and dyeing methods have varied in different geographical regions (Kirby et al. 2014, 2). In archaeological research, dyed textiles can be used for identifying locally made products and trace the trade connections and the spread of cultural influences. The dye compounds of the archaeological finds, the dye history of Finland and lack of local rock alum provide the background to my research questions:

- 1) **What were the Late Iron Age dye sources in Finland?**
- 2) **What were the dyeing techniques in the Late Iron Age Finland?**

My answers are provided by combining data gained from the dye analyses of archaeological samples (Chapters 3 and 5, Papers I, II, III and IV, Appendices 2–4) and from reference dyeings (Chapters 3–5, Appendix 5, Paper V), dyeing experiments (Chapters 3–5, Paper V) element analyses (Chapters 4–5, Appendix 6) and from Finnish folklore concerning dyeing (Chapters 4–5, Paper V). Results are discussed in Chapter 6 and conclusions are presented in Chapter 7.

## 1.2. Context and chronology

Most of the analysed fragments are from Late Iron Age inhumation burials: there are 10 samples (6 fragments) from Kaarina Kirkkomäki in Turku, 4 samples from Rikala in Halikko (1 fragment), 5 samples from Tuukkala in Mikkeli (3 fragments), 1 from Yliskylä in Perniö (1 fragment) and 7 samples from Luistari in Eura (3 fragments). These textile fragments have been survived near the bronze objects that have prevented microbiological activity and thus protected the finds from decomposition (**Fig. 1**).

During the Iron Age, ideological changes caused a shift from cremation to inhumation burial habits and this can be connected to the spreading of Christianity (Wessman 2010, 77). No textile finds are available from the *Early Roman Iron Age* (500–0 BC), but few go back to the *Roman Iron Age* (AD 0–400) and some to the *Migration period* (AD 400–575) and the *Merovingian period* (AD 575–800). In the south-western Finland inhumation burial habit began during the 6<sup>th</sup> century AD, whereas elsewhere in Finland this process was slower. Most of the prehistoric textile finds are from the *Late Iron Age*, especially from the *Viking Age* (AD 800–1025) and from the *Crusade period*, which continued in western Finland to AD 1150 (or 1155, depending on the scholar) and in Eastern Finland until AD 1300. Grave goods are connected to non-Christian burial habits, which vanished at the end of the Late Iron Age due to Christianity (Wessman 2010, 78).

Only during the middle of the Viking Age men's garments had more spiral ornamentation, but these finds are from cremation burials without any textile finds (Lehtosalo-Hilander 2001, 77). After that, more prehistoric textile fragments from male burials have been preserved, often near belt fittings and buckles, but remains of jackets, rectangular cloaks, tunics and leg wraps are also found. During the Late Iron Age, bronze jewellery, and bronze spiral ornamentation bordering the garments and applied bronze spiral rosettes (Vahter 1928) were more frequent in female burials and accordingly, there is more textile material preserved from female burials. This material consists of dresses, aprons, head-dresses and ribbons. Less bronze spiral decoration was used for textiles below the hem line. Thus shoes (Pälsi 1936; Itkonen 1960) and leg wraps (Riikonen 2006a) are rare remains.

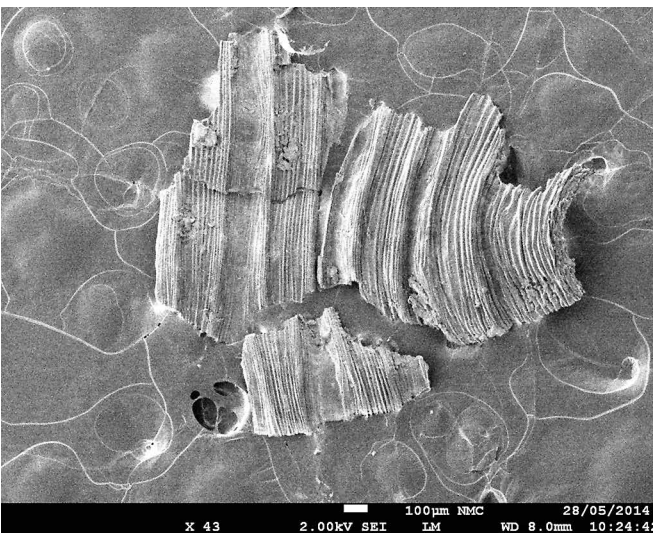
Not everyone was buried in cemeteries – these were burial places of rich, ruling families with high a status in society (Riikonen 2004, 29–30; Pihlman 2004, 66–67). Respectively the burial textile finds presumably represent the fabrics, decoration patterns and dyes of upper class people. Based on the number of burial goods and metal objects found in the graves, the objects in the female's graves i.e. spiral ornamented fabrics, jewellery, knives etc. were not with lesser value than those in the male's graves i.e. swords, spearheads, other weapons etc. (Lehtosalo-Hilander 1982a–c). No textile fragments have been found in Finland in the Iron Age settlements, which consist of finds such as spindle whorls, loom weights and bone needles as an evidence of textile making (Vuorinen 2009; Mikkola 2006; Alenius et al. 2007).

The textiles found in the graves have been seen as Late Iron Age festal garments (Schwindt 1893, 186), which were not worn in everyday life (Riikonen 2005a, 45). The garments probably reflected the status that the persons had during their life (Riikonen 2005a, 37), for example the women possibly in their wedding dress (Riikonen 2005b, 240). There is less material from male burials and next to nothing from child burials. In many cases children were dressed as miniature adults on the basis of the preserved placing of brooches, and other jewellery and grave goods (Schwindt 1893, 145; Lehtosalo-Hilander 2000, 224–226). A possible human body louse suggests (**Fig. 2**) that the garments were not specifically funeral clothes but were articles of everyday use, since human body lice do not survive long without human blood.





**Figure 1. Map of the sites of the archaeological samples.**  
(Drawing: K. Vajanto)



**Figure 2. Broken remains of a possible human body lice from Luistari grave 56.**  
(K. Vajanto, Nanomicroscopy Centre Aalto University).

There are no textile fragments found in the Iron Age settlements in Finland. Thus fragments from the shipwrecks found in Lapuri (2 fragments) and Egelskär (1 fragment) were included in my dissertation. These finds have been dated to the 13<sup>th</sup> and 14<sup>th</sup> century AD and are thus contemporary with the samples from the Tuukkala burials. These textiles had been survived in a completely different type of archaeological context, one in which the textiles were not preserved through direct contact with bronze. I presumed that these fragments provide comparison data especially concerning the mordants and environmental contamination.

The Iron Age was followed by the *medieval period* i.e. *the Middle Ages*. The medieval period continued in Finland until 1523 AD, when Gustav I of Sweden (Gustav Vasa) became the ruler of Sweden and Finland. The medieval Finnish textile finds are from urban contexts, especially from Turku. The Late Iron Age finds are predominantly locally made garments, while the medieval finds reflect international connections acquired via the Hanseatic trade (Hammarlund et al. 2008, 78, 88; Kirjavainen 2009).

Wool types remained more or less the same from the Iron Age to the Middle Ages (Kirjavainen 2002), but spinning and weaving crafts changed with the medieval introduction of the horizontal loom and the spinning wheel (Kirjavainen 2003b). During the Late Iron Age weaving and dyeing were women's crafts (Kirjavainen and Riikonen 2005, 2007a). In the medieval urban centres these crafts were carried out by professional men (Kirjavainen and Riikonen 2005, 2007a), but possibly small scale household dyeing was performed by women, such as the ethnographic evidence from the 19<sup>th</sup> century AD suggests.

### 1.3. A brief research history

#### 1.3.1. In Finland

Dyes have played a minor role in Finnish textile research. Actually this is just for good, because before the modern (U)HPLC applications the dye analyses required big sample sizes, which was catastrophic for the scanty preserved textile material. My estimation is that approximately only 1% (or less) of the original amount of fabric has survived. The textile research has thus focused mainly on visual analysis by observing the placement of the jewellery, seams, warp and weft courses. By these observations and experimental archaeology it has been possible to reconstruct Late Iron Age female costumes (Appendix 7). In general, the Finnish costume reconstructions consist of several colourful garments, of which some have been dyed with natural dyes, but most with the synthetic dyes.

One aim of the first costume reconstructions was to decipher the style of garments of the heroes of the *Kalevala*, Finland's national epos (Kalevala 1949; Lehtosalo-Hilander 2001, 17–19; Fewster 2006; Appendix 7). This is understandable, because the *Kalevala* to some extent describes the shade of colours and the bronze decorations that are present in the archaeological textiles (Lehtosalo-Hilander 1987).

The colours of the *Aino costume* were based on pure imagination. The costume was in fact intended to be a theatrical garment (Lehtosalo-Hilander 1972, 30). The *Kaukola costume* (1956), the *Ancient Karelian costume* (1952) and the *Tuukkala costume* (1937) are results of visual analysis (Schwindt 1893; Heikel 1889; Appelgren-Kivalo 1907; Lehtosalo-Hilander 1988 and 2001). The blue apron and veil of the Kaukola costume were dyed using tropical indigo (*Indigofera tinctoria*), that was based on indigotin detected by wet chemistry analysis (Lehtosalo-Hilander 1984, 38), while the dress was dyed with crottle (*Parmelia saxatilis*) just by following a pure guess (Lehtosalo-Hilander 1984, 38).

The blue dye of the dress of the *Tuukkala costume* was visually observed by optical microscopy (Lehtosalo-Hilander 2001, 37–39; Kirjavainen and Riikonen 2005). The cherry red colour of the first *Perniö costume's* dress (1925) has no correspondence to the archaeological finds (Lehtosalo-Hilander 1973 and 2001, 35–37; Riikonen 2006a, 19). The updated version of the *Perniö costume* (1980s) has a blue apron, which shade of colour is based on the indigotin detected by wet chemistry, while the white colour of other fabrics is based on analyses made using optical microscopy (Wikström et al. 1972; Riikonen 2006a, 19; Lehtosalo-Hilander 1984).

The yarns of the *Eura costume* (1982) were dyed with tropical indigo (*Indigofera tinctoria*), heather (*Calluna vulgaris*), birch leaves (*Betula* species), stinging nettle (*Urtica dioica*) and roots of Northern and white bedstraw (*Galium boreale* and *Galium album*). Indigotin was found by wet chemistry analysis, while red was based on visual analysis (Lehtosalo-Hilander et al. 1982, 41; Lehtosalo-Hilander 1984, 48–49 and 2001).

The peplos dress of the *Masku costume* (1984) was dyed with crottle (*Parmelia saxatilis*), according to a visual analysis (Tomanterä 1984). Its apron and shawl cloak fragments were defined blue in visual analysis and by wet chemistry tests (Lehtosalo-Hilander 2001, 28; Wikström et al. 1972).

The dyes of the *Kirkkomäki costume* (1991) were defined by the means of visual analysis and wet chemistry (Riikonen 1990; Riikonen 2003; Riikonen 2006a, 27–32) and TLC analysis (Kirjavainen and Riikonen 2007; Walton, 2001a). Indigotin was detected in several fragments. Its source was presumably woad (*Isatis tinctoria*), which was used to dye yarns for the reconstruction by applying experimental archaeology concerning woad and urine vats (Hannusas and Raitio 1997). Visual analysis determined the warps of the shawl cloak as red (Riikonen 1990). The warps of the first *Kirkkomäki costume* reconstruction were dyed with anthraquinones of surprise webcap (*Cortinarius semisanquineus*) (Kiviniemi 1999). By TLC analysis, red tannins were detected (Walton 2004a) and the warp yarns of the updated shawl cloak (2009) of the *Kirkkomäki costume* were dyed with tannin-containing hazelnut husks (*Corylus avellana*). This dye source was selected because rich amounts of hazel nut husks have been found in cultural layers of medieval Turku (Lempiäinen 2003, 332).

Tannin dye detected in the TLC analysis served as a source of inspiration for the red peplos dress and red apron of the *Mikkeli region costume* (1996), while its blue tunic and blue shawl cloak were based on optical microscopy (Kirjavainen and Riikonen 2005; Walton, 2004a; Riikonen 2006a). TLC and HPLC analyses have also been applied on some medieval textiles with a positive match for tannin, Dyer's madder (*Rubia tinctorum*), bedstraws (*Galium* sp.), indigotin and weld (*Reseda luteola*) (Walton 2001b; Kirjavainen 2002, 2003b and 2012).

Materials from the Early Modern Oulu Cathedral and surrounding smaller churches have been researched by current scientific methods by applying archaeology, textile archaeology, dyes and forensic archaeology (Lipkin et al. 2015). Multidisciplinary textile research has been carried out by the Turku relic project. These textiles found in the Turku Cathedral have been examined from archaeological, textile archaeological and conservation points of view (Arponen 2011; Taavitsainen 2011; Karttilla 2014; Kirjavainen 2012). In addition, a plant dyed reconstruction – a female's dress – has been made based on the medieval textile fragments found in the urban contexts in the excavations made in Turku (Pasanen 2015).

### 1.3.2. In Europe

The interest on dye research has varied a lot within Scandinavia. In Sweden the published dye research is limited to the Högom textiles (Nockert 1991, 73–75; Hofenk de Graaff 2004). In Norway, TLC analyses



have been made on the textiles of the Oseberg burial and Veien and Enebø/Eide textiles (Walton 1988a; Ingstad 2006; Vedeler 2014). In Denmark textile fragments from the Bronze Age and Iron Age and the medieval period both on the mainland and in Greenland have been analysed with TLC, many of them also with HPLC (Walton 1988a, Walton 1991, 2004b; Vanden Berghe et al. 2009). In general, the Danish dye research has been very well applied to textile research and the results provide a possibility to observe changes in the dyeing tradition over time.

In Estonia HPLC has been recently applied on the Iron Age and medieval burial textiles (Rammo and Matsin 2015). Some papers have been published on the Russian dye research, where molecular spectroscopy and chromatography have been applied to examine the Pazyryk textiles (Rudenko 1970; Balakina et al. 2006).

The Anglo-Saxon textiles found in York and the Hiberno-Norse textiles found in Dublin have been analysed using TLC (Walton and Hall 1997; Walton 1988b). The analysis indicated that most of the fragments were dyed and there were certain fashion colours in different sites (Walton 1988b). The dyes of Hochdorf textiles (Banck-Burgess, 2012) and the Thorsberg textiles (Walton 1988a, 156–157; Vanden Berghe and Möller-Wiering 2013) show high skill of dyers who were able to dye with different dyeing methods.

Many of the Bronze Age and Iron Age textiles from the Hallstatt salt mines have been analysed by HPLC (Hofmann-de Keijzer et al. 2005, 2013a, 2013b). The analysed textiles indicate changes in the dyeing traditions, dye transport and cultural exchange. In general, the Iron Age dye palette was rich and double dyeing was also known, allowing the production of more shades of colours.

## 1.4. Natural dyes – an overview

Dyeing with natural dyes can be done with an organic colouring substrate that can be obtained from plants, insects, mushrooms, lichens and molluscs. In general these contain *organic colourants*. Most organic colourants are water soluble *dyes* that usually need a metal salt or an organic mordant to bind the colour bearing chromophores with the textile fibres. The *pigments* are insoluble in water and rare amongst the organic colourants. Natural dyes were used in great quantities up to the invention of synthetic dyes in the second half of the 19<sup>th</sup> century AD, after which the use of natural dyes ended almost completely within a few decades.

### 1.4.1. Tannins

Tannins are present plant materials such as in tree barks, nutshells, and oak galls. The *condensed tannins* are colourful, mostly reddish and consist of big to very big molecules (Cardon 2007, 696). The *hydrolysable tannins*, such as ellagic acid, are lighter in colour and smaller (Cardon 2007, 692–696). In tanning, the condensed tannins penetrate the spaces between the leather's collagen fibres and dye the material, preventing it from rotting (Cardon 2007, 691). Dyeing wool with tannins is close to tanning leather. In addition, tannins can work as plant mordant for other dyestuffs and fix them both on wool and plant fibres (Tetri 2008, 75–78; Vajanto, K. 2013a).

Determining tannin dyes from the environments contamination is not easy. Ellagic acid-equivalent and rhamnetin-equivalent have been detected in the Hallstatt textiles (Hofmann-de Keijzer et al. 2013b, 161). In Danish Early Iron Age (500–0 BC) textiles, ellagic acid was considered to originate on intentional dyeing rather than from bog contamination (Vanden Berghe et al. 2009 and 2010). Ellagic acid was

detected in the Thorsberg textiles in a warp yarn with indigotin, but not in the other yarns, suggesting an intentional dyeing rather than contamination (Vanden Berghe and Möller-Wiering 2013). Probable tannin dye, not a contamination, has been detected in Greenlandic medieval textiles found in Herjolfsnæs (Walton 2004b, 90).

Iron with hydrolysable tannins produces black dye (Schweppe 1993, 570–571), but causes also degradation of wool fibres (Daniels 2001). Possible evidence of the use of tannins has been found in the Hallstatt textiles (Hofmann-de Keijzer et al. 2013b, 156–157). The geographically nearest archaeological textile finds with tannins and iron mordant are from medieval Novgorod (Kublo 2012, 254).

### 1.4.2. Direct dyes

Some dyes are so-called *direct dyes*, in which hydrophobic interaction allows the dye to attach directly to the fibres. The method is easy but colour fastness and lightfastness are not very good since the hydrophobic interaction between the fibres and chromophores is not strong (Räsänen et al. 2015, 212). Direct dyeing technique was known already in Egypt in the 14<sup>th</sup>–12<sup>th</sup> centuries BC, where it was applied in dyeing with safflower (*Carthamus tinctoria*) (Barber 1992, 227, 232). Safflower gives a caramel pink shade on silk and cotton (Kirby et al. 2014, 60).

The wall paintings of Akroiri at Thera represent people picking stigmata of crocuses (*Crocus sativa*) either to use them as a spice or as a yellow direct dye (Cardon 2007, 305–306). Saffron was used to dye linen and silk bright orange (Kirby et al. 2014, 60; Cardon 2007, 305–306). Possible crocus dye, a crocetin-equivalent, has been found in a woollen Hallstatt textile, dated to the local Iron Age, 850–350 BC (Hofmann-de Keijzer et al. 2013b, 155, 161).

### 1.4.3. Mordant dyes

The most common dyeing technique is *mordant dyeing*. In dye baths the fibres have a positive charge, while the dyestuffs have a negative charge and as result, the ion bonds are formed between the wool fibre and the dye compounds (Räsänen et al. 2015, 209–210). Metal mordants add lightfastness to the dyes and increase the effect of dyeing by adding points to which the dye compounds can attach (Räsänen et al. 2015, 202).

Aluminium, iron, copper, tin and chrome and salts can be added to dye baths intentionally to utilise their mordanting properties. Alum mordant can be obtained from mined alunite, or aluminium-containing clays or bauxite in chemical processes. In addition, plant mordant can be obtained from plants such as clubmosses (*Lycopodium* species) which accumulate aluminium from the soil. Iron and copper mordants intensify the shade of colour and produce different shades on wool when dyeing (Dean 2014, 120; Kirby et al. 2014, 49–59). Sometimes iron and copper leak from the dyeing vessels or originate in the water used in a dye bath i.e. well water, lake water, rain water etc. and cause non-intentional mordanting.

#### 1.4.3.1. Anthraquinones

Red dye compounds such as alizarin and purpurin that are available from the roots (rhizomes) of the Rubiaceae family of plants. The oldest find, which suggest the use of Dyer's madder (*Rubia tinctoria*) is a 5000-year-old dyed cotton fragment found in a silver vase at Mohenjo Daro, in the Indus Valley (Barber 1992, 232). The mummies of Ürümchi near Takla Makan desert, from 1600–200 BC, were dressed in

red and blue dyed textiles that were preserved by the coldness and dryness of the environment (Barber 1999; Liu et al. 2013). From the European Iron Age, there are several finds dyed using Dyer's madder and/or bedstraws (*Galium* species). In medieval Europe, Dyer's madder and insect reds were the most important dyes for red (Chenciner 2000; Munro 2009).

Dark crimson and scarlet red textiles can be dyed with insect anthraquinones (Schweppe 1993, 560–561). Kermes insects (*Kermes vermilio*) live in the kermes oaks (*Quercus coccifera*) in Mediterranean areas (Cardon 2007, 609–611) and contain kermesic acid as main colorant. Polish cochineal (*Porphyrophora polonica*) lives on the roots of perennial knawel (*Scleranthus perennis*), and was collected especially in Poland. Lac dye is the red dye gained from shellac which is derived from the stick lac that is produced by the lac insect (*Kerria lacca*) on tropical trees in Southern and Southeastern Asia, especially in India. Aramenian cochineal (*Porphyrophora haemellii*) grows in the roots of grass species in Western Asia and Mount Ararat. These insect species contain carminic acid and kermesic acid, whereas lac dye contains laccaic acid (Hofmann-de Keijzer et al. 2005, 62).

An insect dye, similar to carminic acid, was detected in two Hallstatt textiles, dated to the local Early Iron Age (850–350 BC) (Hofmann-de Keijzer et al. 2005, 60, 62; Grömer and Rösel-Mautendorfer 2013, 412, 491–492; Hofmann-de Keijzer et al. 2013a, 2013b). Indigotin, possible kermes and lichen orchil dyes were detected in the Celtic Hochdorf textiles found in Germany (Banck-Burgess 2012, 145). Kermesic acid, carminic acid, plant anthraquinones and indigotin were used to dye the Pazyryk textiles ca. 500–200 BC (Balakina et al. 2006).

When Christopher Columbus discovered the route to the Americas, new dye insect species, such as Mexican cochineal (*Dactylopius coccus*) were found. This insect was cultivated in *Opuntia* cacti by the Aztecs and the Maya people. This cochineal soon replaced traditional European insect dyes, because it was cheaper and its shade of red was brilliant (Schmidt-Przewoźna 2005; Cardon, 2007, 631; Schmidt-Przewoźna 2008). Mexican cochineal contains carminic acid as main dye, similarly like Polish cochineal or Aramenian cochineal.

#### 1.4.3.2. Flavonoids

Flavonoids are present in all green plants and the identification of a certain dye plant from an archaeological textile is difficult or nearly impossible. From historical sources it is known that the yellow colours in Europe were dyed using weld (*Reseda luteola*), Dyer's broom (*Genista tinctoria*) and saw-wort (*Serratula tinctoria*). These plants contain apigenin and luteolin as main colourants. Yellow flavonoids were already used in the Bronze Age Hallstatt (1600–1200 BC) (Hofmann-de Keijzer et al. 2013b, 160–161). In Scandinavia, the oldest evidence of flavonoid dyes is from Early Iron Age, found in the skirt of the Huldremose woman (210–40 BC) (Vanden Berghe et al. 2009 and 2010, Mannering 2010, 22). From the Throrsberg textiles, flavonoids suggesting dyers broom and/or weld or saw-wort have been detected (Vanden Berghe and Möller-Wiering 2013).

Yellow dyes and blue indigotin can together produce green. In Europe this was usually done with weld, saw-wort, flax leaved daphne (*Daphne gnidium*) and Persian berries (*Rhamnus* species) (Cardon 2007, 173, 179, 183, 189). In Finland and Latvia there is data about using the anthocyanin type of flavonoids obtained from blue flowers and berries to dye wool bluish or turquoise (Bielenstein 1935; Vajanto 2013b).

Flavonoid types of dyes that produce pink, red and purple shades on wool were obtained from tropical dye trees, which were exploited near to extinction. Sandal wood (*Pterocarpus santalinus*), sappanwood (*Caesalpinia sappan*) and other species of Old World were used for red dyes (Cardon 2007, 286–288). After the colonisation of the New World, logwood (*Haematoxylum campechianum*) trunks were transported to Europe for purple and black colours and redwood (*Caesalpinia echinata*) for red shades (Schweppe 1993, 568–569).

#### 1.4.4. Vat dyes for indigoids

*Vat dyeing* is performed in an alkaline bath via reduction-oxidation process. This technique is applied to indigoid pigments obtained from plants that produce precursors of indigotin, and to purple-giving molluscs with dibromoindigo and to lichens that yield orchil (Cardon 2007; Räisänen et al. 2015, 158–159). The reduction process was traditionally done by fermenting the alkaline dye bath using ammonia-containing human urine. Wood ash lye or another alkaline substrate was added to control the pH-value.

Indigotin is one of the most commonly detected dyestuffs in prehistoric and historical textiles (Walton 1988a, 1986, Hofmann-de Keijzer et al. 2005, 2013a, 2013b; Paper I). The oldest indigo-dyed textiles are from the Middle Kingdom Egypt (Balfour-Paul 2011, 13). In Europe, the traditional source of indigotin was woad (*Isatis tinctoria*) (Cardon 2007, 335–408). During medieval times, woad was cultivated in large quantities for example in Germany and France for professional woad dyers (Cardon 2007; Balfour-Paul 2011).

In tropical Africa, the indigotin was derived from *Philenoptera* species, in the Far East from Japanese indigo (*Polygonum tinctorum*) and Americas from several local plant species. In India, tropical indigo shrub (*Indigofera tinctoria*) was used to produce strong indigo pigment. That pigment was traded from the colonies via maritime routes, even up to the North in ships like *Vrouw Maria* (Alvik et al. 2014). Eventually tropical indigo pigment replaced woad (Balfour-Paul 2011, 55–57), although the tropical indigo pigment was forbidden in many European countries from the 16<sup>th</sup> century AD onwards.

Tyrian purple was extracted from molluscs such as *Hexaplex trunculus*, *Bolinus brandaris* and *Purpura haemastoma* (Cardon 2007, 554). The Phoenicians invented purple dyeing about 1800–1600 BC (Cardon 2007, 571). The purple pigment was very light-fast and thus the purple dyed textiles were very precious. Over time, these molluscs became increasingly rare and eventually in the Byzantine Empire, only the emperor's family was allowed to wear the textiles dyed with royal purple.

#### 1.4.5. Lichen dyes

Lichen dyestuffs, such as certain anthraquinones, depsides and depsidones are found in species of crotches (*Parmelia saxatilis* and *Ochrolechia tartarea*), rock tripe (*Lasallia pustulata*) and yellow wall lichen (*Xanthoria parietina*) (Stenroos et al. 2011). In crotche dyeing (*Parmelia saxatilis*, Ref. 52) the lichen dyestuffs work both as an *organic mordant* and a *dye*; heating changes the colourless precursors of colourants to russet shades and produces a very fast bond (Cardon 2007, 704).

Lichen purple can be produced in an alkaline vat from many lichens that contain orsellinic acid, or its close relatives, longer depside molecules with an orsellinic acid core (Casselmann Diadic 2001; Cardon 2007). The orsellinic acid turns to colourless orcinol, which with oxygen turns to orchil. This dyeing is close to indigo and woad dyeing, but does not need not constant warm temperature (Paper V).

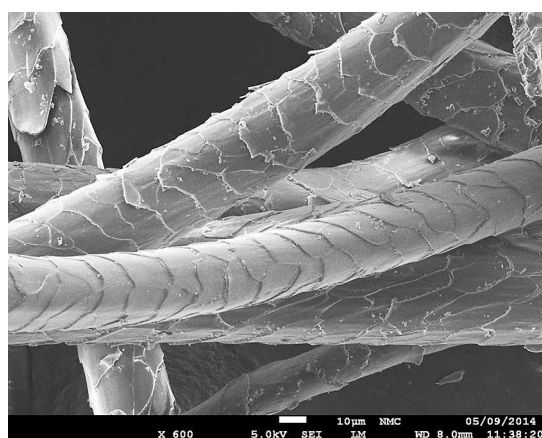
In the Mediterranean region lichen purple was used to imitate the expensive colour of mollusc purple, as can be seen in the practical dyeing recipes of the *Stockholm Papyri*s (Hofenk de Graaff 2004, 275). Oldest preserved textiles with lichen orchil have been found in 9<sup>th</sup> century BC Hallstatt textiles (Hofmann-de Keijzer et al. 2013b, 150).

## 1.5. Textile archaeological background

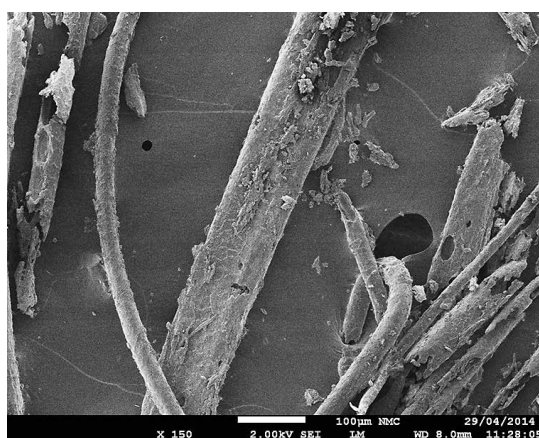
During the Late Iron Age, several fibre materials and textile techniques were applied in textile making in Finland.

### 1.5.1. Fibres

Finnish archaeological textiles are predominantly woollen and this was indeed the case in the analysed samples (Appendix 2). As a protein fibre, wool withstands the acidic Finnish soil better than plant fibres. Over time the wool degrades and the fibres surface scales disappear and the inner microfibrillar structure becomes visible (Figs. 3–6).



**Figure 3. Wool of modern Finnsheep.** (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 4. Degraded outer coat hairs and underwool from Kaarina Kirkkomäki grave 27, KM 27025:H27:235 (Sample 13).** (K. Vajanto, Nanomicroscopy Centre Aalto University).

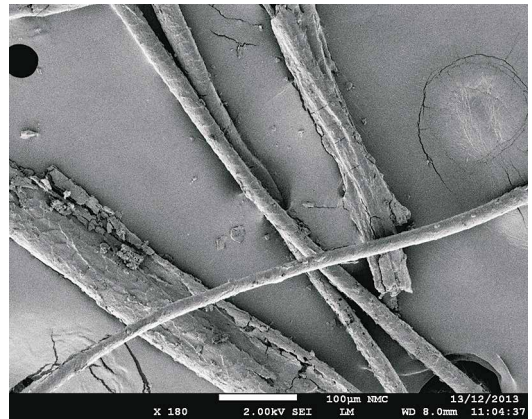
Iron Age sheep in Finland were double coated, i.e. the fleece consisted of underwool and outer coat hairs. Wool was available in many different colours (Paper IV). The role of sheep wool in the textile history has been remarkable, because most animal hair is too short, too hard or too slippery and thus has poor spinning properties. Exceptions are mohair and cashmere of certain goat (*Capra*) species, the hair of Angora rabbit (*Oryctolagus cuniculus*), and the hair of certain camelid species (*Camelidae*). In the North, fine mohair fibres have been found in the Oseberg burial (Christensen and Nockert 2006, 389) and through international trade these fibres might have been transported to Finland too.

Other animal hair has been spun only occasionally. The coarse hair of the domestic goat (*Capra aegagrus hircus*) has been found in caulking and packing textiles in medieval Turku (Kirjavainen 2011,

247; Kirjavainen 2003b, 17). In Greenland, there are yarns spun of dog (*Canis familiaris*) hair, goat hair and the white hair of hare (the *Lepus* species) (Østergård 2004, 71, 117; Østergård 2005, 81). Maybe this was done because of a lack of sheep's wool, or it might have been a Northern speciality: during the 17<sup>th</sup> century AD soft, white hare wool was knitted into caps amongst the Sami people in Lapland (Itkonen 1979, 222). In Eastern Finland, horse (*Equus ferus caballus*) tail hairs were used make bronze spiral ornamentation. Coarse deer (the *Cervini* species) hair mixed with wool has been reported in the Kekomäki textiles (Schwindt 1893, 154–155, 182). These fibres might be outer coat hairs or kemps. Sometimes these coarse fibres have been misidentified as deer fibres (Ryder 1988, 137).



**Figure 5. Wool fibres from Lapuri shipwreck SMM 2592:8 with medullated outer coat hairs and fine underwool fibres (Sample 16a). (K. Vajanto, Nanomicroscopy Centre Aalto University).**



**Figure 6. Degraded, dyed wool fibres from Luistari, KM 18000:1702 (Sample 1b). (K. Vajanto, Nanomicroscopy Centre Aalto University).**

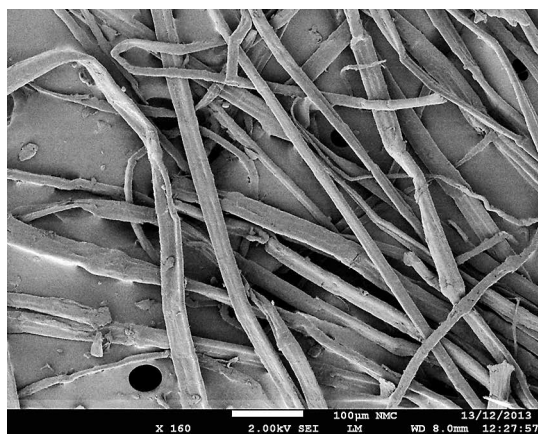
Silk (*Bombyx mori*) is protein fibre and can be dyed with natural dyes like wool. Silk is rare in Finland: the finds consist of some remains of silk brocade bands and fabrics (Schwindt 1893; Geijer 1938; Tomanterä 1978 and 2006a, 45; Lehtosalo-Hilander 1982b, 171 and 1982c, 49; Vedeler 2013 and 2014). Silk fabrics were traded in Western Europe via the Silk Routes, whereas in the Northern Europe silk presumably arrived via the river routes through Russia (Vedeler 2014).

Textiles made of vegetable fibres are far rarer in the Finnish archaeological material than woollen ones, because cellulose fibres withstand acidic soil poorly. Plant fibres are more difficult to be dyed using natural dyes. This suggests that textiles such as shrouds, coverings, shirts and neck bands made of flax (*Linum usitatissimum*), hemp (*Cannabis sativa*) and nettle (*Urtica dioica*) were used as white (Riikonen 2007; Tomanterä 2006b; Mäntylä 2011). Possibly the white plant fibre textiles were connected to wealth and luxury (Riikonen 2011).

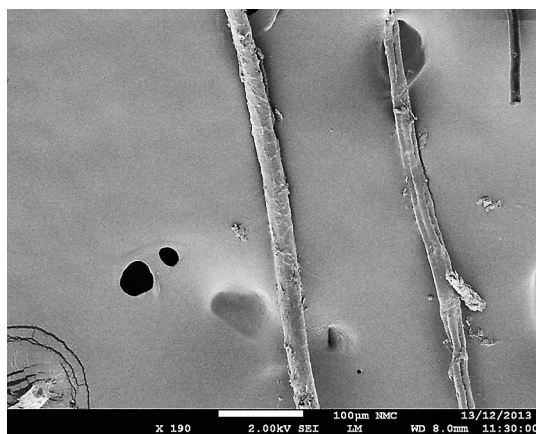
The fine string imprints on clay suggest that nettle yarn was already used in the Corded Ware culture (ca. 2500–2000 BC) (Korkeakoski-Väisänen 1993, 23). Iron Age plant fibre textiles were probably made from locally cultivated plants. The oldest flax seeds are from the Younger Roman Iron Age (200–400 AD) settlements from Salo (Aalto 1982) and Spurila in Paimio (Seppä-Heikka 1985), while pollen of the

*Cannabis/Humulus* type, the pollen of hemp (*Cannabis sativa*) and a hemp seed have been found in the Late Iron Age layers of the Orijärvi settlement in Mikkeli (Alenius 2007, 22; Alenius et al. 2007, 179; Vanhanen 2010, 58). Possible nettle fibres were found in Luistari grave 56 (Paper II; **Fig.7** and **Fig. 8**).

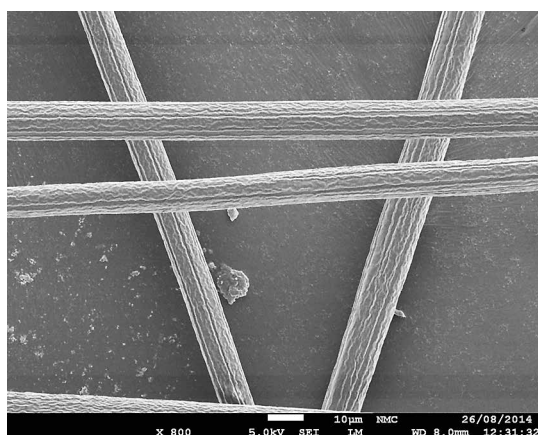
Other plant fibres that were available for the Late Iron Age Finns were seed fibres of rosebay willow-herb (*Epilobium angustifolium*) and hare's-tail cotton-grass (*Eriophorum vaginatum*) (**Fig. 9** and **Fig. 10**). According to ethnographic sources these seed fibres were used in cord making for candle wicks, either alone or mixed with wool (Linnilä et al. 2002, II/177 and III/148).



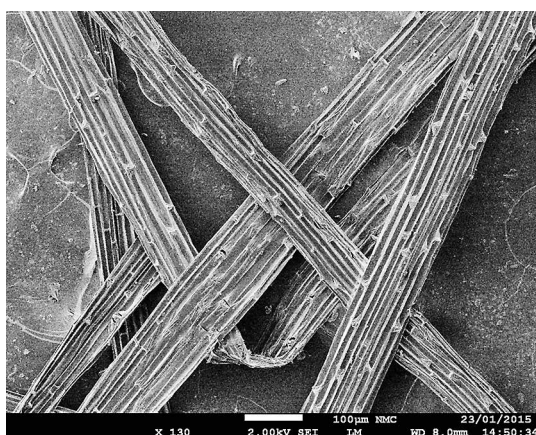
**Figure 7.** Finnish stinging nettle (*Urtica dioica*), modern reference. Dislocations visible. (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 8.** Wool fibre on the left and stinging nettle (*Urtica dioica*) on the right from Luistari 56's nålbinding textile KM 18000:1702. (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 9.** Barbs of rosebay willowherb (*Epilobium angustifolium*). (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 10.** Barbs of hare's-tail cotton-grass (*Eriophorum vaginatum*). (K. Vajanto, Nanomicroscopy Centre Aalto University).

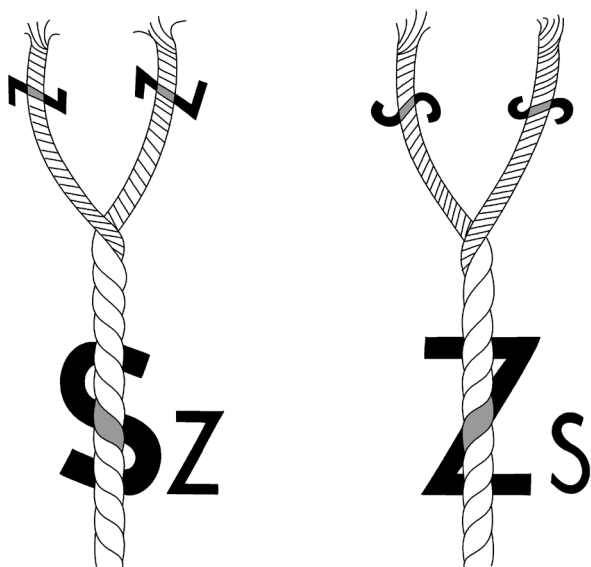
### 1.5.2. Yarn

Yarn is one of the greatest inventions of humankind, and led to the so-called *String Revolution* (Barber 1994, 45). Spinning fibres to clockwise direction produces z-twist, while spinning to counter-clockwise produces s-twist. Yarn can be unplied i.e. single-ply (Emery 1994, 13) or it can be plied; z-spun yarn is plied to Sz-twisted and s-spun yarn to Zs-twisted. If two single plied yarns are used, the yarns are labelled as S2z-ply and Z2s-ply (Gleba and Mannering 2012, 9) (**Fig. 11**). When interpreting imprints of yarns some three-dimensional thinking is needed: imprint in clay is a *negative*, while the yarn is a *positive*. Accordingly, s-spun yarn results in an imprint with a z-twist and z-spun yarn in an imprint with an s-twist (Grömer and Kern 2010).

The spinning angle and ply angle tell how tightly fibres are twisted in yarns. Increasing the amount of twist as well as plying creates stronger yarns, since the fibres are packed more tightly (**Fig. 12** and **Fig. 13**).

The oldest preserved yarn is a rope with S-cabled three Zs-ply tree bast cord from the Palaeolithic cave of Lascaux, made ca. 15 000 years ago (Barber 1992, 40). In Finland, the oldest yarn find is the fishing net of Antrea. It has been made ca. 8100–8400 BC (uncal.  $^{14}\text{C}$  9230±210 BP and 9310±140 BP) (Huurre 1998) with Sz-ply willow (*Salix* species) bast to create a 27 metre long net with 18 pine (*Pinus sylvestris*) bark floaters and 31 stone sinkers (Pälsi 1920; Kujala 1948).

In ancient Egypt and in Neolithic Switzerland flax fibres were spun using the *splice and twist technique* by twisting 60–90 centimetre long flax fibres together by using the fingers (Barber 1992, 44–47; Leuzinger and Rast-Eicher 2011). This technique was also still used by the Sami people in the 17<sup>th</sup> century AD to make yarn from sinew threads (Itkonen 1979). In *draft spinning* the fibres are drafted continuously from a bundle of fibres to the spindle. Its more archaic version is a spinning hook (Bielenstein, 1935, 49). It has been suggested that the draft spinning method was originally created for spinning wool, but was extended to other fibres too (Barber 1992, 50). In Finland, whorls from the Iron Age spindles (drop or suspended) have been found usually in female graves, but also in settlements.



**Figure 11.** The s-spun and Zs-ply yarn and z-spun and Sz plyed yarn (Drawing: K. Vajanto).



Finnish archaeological textiles typically have Sz-plied yarns in warp and z-spun yarns in weft (Bender Jørgensen 1992). In Eastern Finland and Karelia z-spun, single-ply yarns were used in shirts and dresses (Schwindt 1893, 155; Lehtosalo-Hilander 2001, 72; Khvoschinskaia 1983 and 1992). Different spinning directions reflect light differently and create a vivid effect on fabric surface. This so-called spin pattern effect is for example the in the men's cloak fragments found in Luis-tari graves 348 and 844 (Lehtosalo-Hilander 2001, 81).

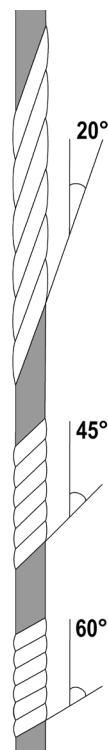
### 1.5.3. Loom weaving

In loom weaving the weft plays an active role, while the warp has a passive role (Seiler-Baldinger 1994, 71–76). The fabric is produced by inserting the weft into a shed that has been formed by interlacing warps, which are lifted and downed in turn. Before weaving, fabrics were made with the twining technique, which produces very similar looking texture in fabrics (Médard 2012, 371–371; Seiler-Baldinger 1994, 31).

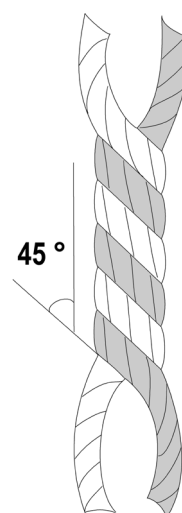
During the European Bronze Age the Danish, Austrian and Swiss textiles were tabbies i.e. plain weave, woven in looms with two shafts. (**Fig. 14** and **Fig. 15**). Basket weave and half-basket weave are derived from tabby. Twill (**Fig. 16**) became the predominant structure of weaving during the Central European Bronze Age (ca. 2200–1000 BC) (Rast-Eicher 2005, 128). Twill is connected to the availability of wool yarns and the four-shaft loom (Bender Jørgensen 1992, 120; Gleba 2012, 3644). The oldest Finnish woven fabric has survived inside a bronze arm ring found in Korvala in Sauvo (Riikonen 2006a, 7), dated to the Older Roman Iron Age (1<sup>st</sup>–2<sup>nd</sup> century AD) (Schauman-Lönnqvist 2000). In the site of Kaakkuri, a few fragments dated to a slightly younger period have survived in quite similar conditions (Mäkivuoti 2009).

The Sz/z and 2/2 twill structure is the most common textile type in Finnish Late Iron Age wool textiles; it has been called as the *Pappilanmäki type* (Bender Jørgensen 1992, 96, 140). In these textiles the thread count varies, but typical are 10–16/7–11 yarns per centimetre, although some woollen fabrics have thread counts of 20/20, 7/4 and 6/6. Broken twill that forms a zigzag texture in the fabric was used in Late Iron Age Finland in the female headdresses, waist skirts and leg wraps (Vahter 1952; Tomanterä 1984; Riikonen 2006a). Other textile types and s-pun yarns usually refer to foreign origin.

Diamond twill, chevron, and rippenköper are derived from twill, but are not found in prehistoric Finnish textiles. 2/1 and 1/2 twills (**Fig. 17**) have been connected with the spread of the horizontal



**Figure 12.** Spinning angles of 20°, 45° and 60° in a z-spun yarn. (Drawing: K. Vajanto).



**Figure 13.** Sz-plied yarn with a ply angle of 45°. (Drawing: K. Vajanto).

loom, since this technique has been assumed to be impossible to be woven in warp-weighted loom (Hoffmann 1964, 201–204; Tomanterä 1978, 111–112), but experimental archaeology has indicated that this is not the case (Batzer and Dokkedal 1992, 231–234). In the Finnish material the three-shaft twills have been thought to be imported (Tomanterä 2006a, 45).

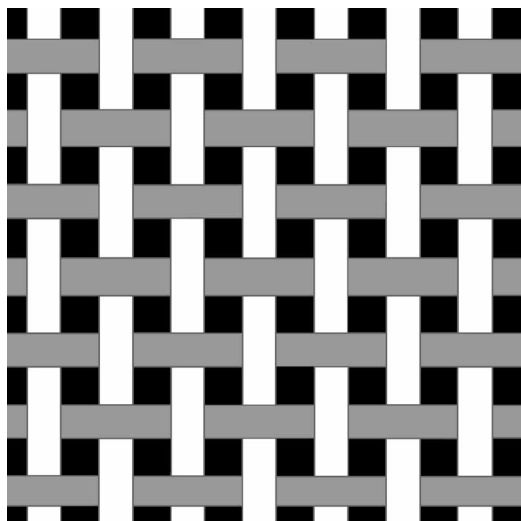


Figure 14. Tabby weave (Plain weave).  
(Drawing: K. Vajanto).

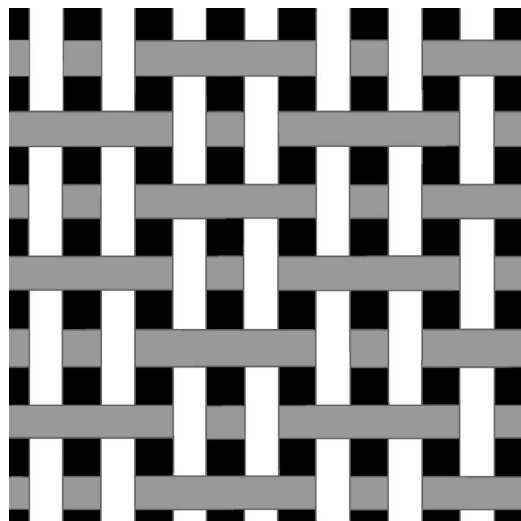


Figure 15. Half-basket weave. (Drawing: K. Vajanto).

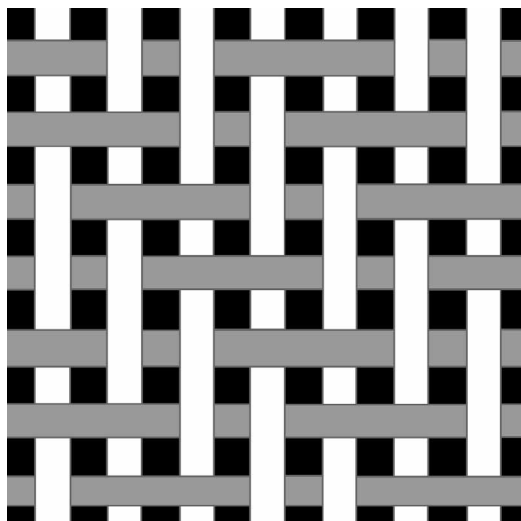


Figure 16. 2/2 twill. (Drawing: K. Vajanto).

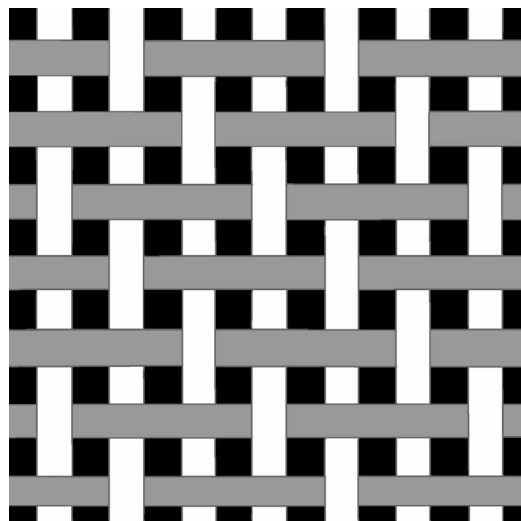


Figure 17. 1/2 twill. (Drawing: K. Vajanto).

Starting borders and tubular selvages suggest that Late Iron Age Finnish fabrics were woven in warp-weighted looms. Warp tension was created by tying the warp yarns to loom weights made of unburnt and burnt clay discs. These items have been found in Late Iron Age settlements and cemeteries. For example, from the settlement of Ihala in Mulli in Raisio, there are 60 kilograms of clay discs (Vuorinen 2009, 221) and from the settlement of Orijärvi in Mikkeli over 7 kg (Mikkola 2006, 5). Finnish folklore of weaving<sup>1, 2</sup> suggests the use of a vertical loom long after the arrival of the horizontal loom, which was introduced in 1350–1500 AD (Lehtosalo-Hilander 1987, 64; Kirjavainen 2003a; Riikonen 2011, 213).

#### 1.5.4. Tablet weaving

Tablet weaving was a commonly known textile technique during the Iron Age in Europe. The tablet woven bands consist of active warps and active wefts (Seiler-Baldinger 1994, 71–76). The warps are threaded into holes of weaving tablets, which can be made of leather, bone or wood, and be rectangular, triangular or polygonal in shape (Pritchard 1994; Gleba and Mannering 2012, 11; Laul and Tamla 2014, 42). The shed is formed by turning the weaving tablets and inserting the weft. Different threading, different tablets positions, different colours of yarns and well as different turning directions such as turning tablets in groups result in countless possibilities for patterns (Grömer 2005a; Ræder Knudsen 1994, 2005 and 2011).

The oldest Finnish preserved tablet woven band is a starting border from Nanhia in Huittinen, dated to the Merovingian period ca. 450–550 AD (Heinonen 1954, 36). The starting and finishing borders from the Finnish Late Iron Age have a so-called brick wall pattern. Typical structures for belt bands are half-turns and the Finnish diagonal technique as well as the tubular selvages that are complicated to weave, but create very detailed patterns and strengthen the selvedge (Penna-Haverinen 2009 and 2010; Karisto and Pasanen 2013). A band from Kirkkomäki has only 24 warps although this is one of the widest bands in Finland (Penna-Haverinen 2010, 195). Very wide tablet woven bands are in the Thorsberg textiles in Germany, in which one band has been woven with over 700 warps (Ræder Knudsen 2011, 171–172).

The Finnish tablet woven bands and ribbons were traditionally woven in a horizontal warp, which was fastened by a stick placed between wall logs, and tightened with a weaving clasp at the waist (Merisalo 1985). After the prehistoric period, the rigid heddle weaving replaced tablet weaving, but retained Late Iron Age tablet woven patterns (Schwindt 1893, 156; Kaukonen 1968). There are folkloristic names for these patterns, such as *revonennä* “fox nose” and *siivilänpesonen* “sieve nest” (Schwindt 1982; Karisto and Pasanen 2013), but it is unclear whether these same names were used by prehistoric weavers too.

#### 1.5.5. Nålbinding

The nålbinding technique is known also as looping or knotless netting (Hald 1980). There is only one active element, the yarn, that is looped around itself in various courses to form different textures and densities (Vajanto 2003, see especially the videos). Fragments made with the nålbinding technique have often been found near the hand bones, and interpreted as the remains of mittens. However, this interpretation has been criticised, because it is largely based on the ethnographic evidence (see Paper II).

1 *Pantiin kangas kankahille, aivinainen alkehille, liinanen liki lakee.* “They set up a warp for fabric, originating from flax, linen near the roof.” Suomen kansan vanhat runot I:V1:751. Niemi 1908.

2 *Seinän kuttoo seisovillaa, puoli seinää polvisillaan.* “A fabric is woven by standing, half of it on the knees.” Suomen kansan vanhat runot I:V1:789. Niemi 1908.

### 1.5.6. Braiding and plaiting

Diagonal-plaited bands i.e. finger woven sashes or bands have multiple active elements that interlace each other in turn (Seiler-Baldinger 1994, 38–39). Using differently coloured warps it is possible to produce diagonal patterns. The Finnish diagonal-plaited bands were often made with an odd number of warps, e.g. 21 or 19. One band from Ristinpelto in Lieto had 25 warps (Vahter 1945). The *sprang* technique produces a texture resembling the diagonal-plaited bands, but no evidence of prehistoric *sprang* has been found in Finland. This technique might have been introduced to Finland during the medieval time (Nissinen 1938, 84; Vahter 1945, 217–218).

The oldest preserved Finnish woollen braid is from a cremation burial from Spurila in Paimio, dated to the older Roman Iron Age (1<sup>st</sup>–2<sup>nd</sup> centuries AD). The find consists of a bronze needle of the shepherd's crook type and undyed, reddish and bluish fibres (Riikonen 1991, 91–93). From the Late Iron Age, there are several braided and plaited bands, often made with colourful yarns (Sarkki 1979).

### 1.5.7. Shawl cloak

The Finnish Late Iron Age shawl cloaks found in female burials were rectangular, woollen and ca. 90–100 x 150–160 cm in size, usually woven in 2/2 twill. These textielies were often dark blue and decorated with bronze spiral ornaments. There are sub types that differ from each other in the structures and the setting of the spiral decorations (Hirviluoto 1973).

The closest parallels for the Finnish blue shawl cloaks are the woollen, dark blue *villaine* garments from the female burials of Late Iron Age Latvia, but these textiles have a more abundant metal ornamentation (Zarina 1970, 1988, 1999 and 2006; Ciglis et al. 2001; Žeiere 2006). In addition, the Estonian Siksälä finds from the 12<sup>th</sup>–15<sup>th</sup> centuries AD have remains of shawl cloaks that are dark blue and metal decorated; some of the Siksälä shawl cloaks have geometric patterns woven using blue woollen warps and white linen wefts (Laul and Valk 2007, 51, 55; Valk et al. 2014).

### 1.5.8. Dress

In Finland, rectangular dress pattern was known already in the 7<sup>th</sup> century AD, based on the equal armed crayfish brooches found as pairs in burials. However, without any preserved textile remains all options concerning dress patterns are open (Lehtosalo-Hilander 1984, 54). During the Viking Age dresses were fastened with round convex brooches that held chest chains. The Crusade period dresses in Western Finland were fastened with small penannular brooches or balanced brooches, while in Eastern Finland the jewellery was more abundant with oval brooches that held thick chest chains.

*Peplos dress* is in the reconstructions of *Eura costume*, the *Masku costume* and the *new Perniö costume*. That dress pattern was open at one side, had folded upper edge and was fastened with two shoulder brooches or pins. However, in the dress fragments of Perniö grave 1 there was vertical seam in the center front and possibly seams at the shoulders (Appelgren-Kivalo 1907, 34, plate VII). This was probably the case also in the dress of the female grave 7 in Köyliö cemetery C, which contained no shoulder brooches (Cleve 1978, 27–28). In addition, there are remains of a waist dress, made of 2/2 broken twill, reconstructed in the *Masku costume* (Tomanterä 1982). The *Kaarina costume* has a folded upper edge in the front fabric, but not in the back fabric – and these fabrics are fastened with two round convex brooches.

In Tuukkala grave 36 the dress was tubular, since there are fringes covering the vertical side seam (Lehtosalo-Hilander 2001, 74). Tuukkala grave 11 contained an oval shoulder brooch, which contained remains of two fabric selvages (Mikkola 2009; Paper IV). This suggests a kind of peplos dress with an unfolded upper edge. This style of dress is in the Hammerun find, excavated in Denmark and dated to the early 3<sup>rd</sup> century AD (Mannering and Ræder Knudsen 2013).

### 1.5.9. Apron

Finnish Late Iron Age aprons were woven of woollen 2/2 twill, usually with tubular selvages, starting and finishing borders. The apron was held at the waist by folding the upper edge, inserting the belt between the fold and tying the belt around the body. During the Viking Age the aprons were ca. 50–90 cm in size, bordered with a narrow bronze spiral row and decorated with bronze spiral rosettes at the lower hem and the fabric corners (Riikonen 2005a, 35). In the mid-11<sup>th</sup> century aprons became narrower, shorter and were decorated with rows of bronze spiral border (Riikonen 2005a, 35). Those aprons were held at waist, for example, by diagonal-plaited belt that was either sewn on or fastened with a loop to the upper corners. In the Karelian finds, the apron hems were decorated with a wide spiral pattern (Schwindt 1893, 118–119, 155, plates 40–42).

Waist aprons were used also in Northern Estonia in the 12<sup>th</sup>–13<sup>th</sup> centuries (Lõhmus et al. 2010; Rammo 2006, 264). In Latvia, aprons were rare but some resemble the Karelian finds (Žeiere 2006, 77). It has been suggested that the aprons and their spiral ornaments had magical and fertility aspects for the females (Riikonen 2005a; Rammo 2006, 265). It should be noted that the Scandinavian aprons (Geijer 1938; Hägg 1974) resemble more or less pinafores and were fastened with straps at the shoulders.

## 2. Theoretical framework

### 2.1. Definition of textile

We all have an impression of what a textile is, but in textile archaeology the question is difficult to answer. Textiles can be seen as items made of flexible cloth, made of fibres by weaving, felting or using other techniques to cover people and things, which would exclude mats and baskets that are made of stiff, self-supporting materials (Barber 1992). Accordingly, the term cloth includes soft and flexible materials used for clothing, containing and covering items (Harris 2012, 62).

Warp and weft are elements of weaving and basketry. Thus twined and woven fabrics as well as baskets can all be seen as textiles (Seiler-Baldinger 1994). Based on this definition, the linden (*Tilia cordata*) bast mat found in Kaarina Kirkkomäki grave 35 (Asplund and Riikonen 2007, 25–26) is not a textile, since its bast straps are not twisted, but used as diagonally interlacing crisscross. Ropes and nets are classified as textiles (Seiler-Baldinger 1994) because these are based on string. For example, the ca. 50 sealing nets from the Stone Age Tuorsniemi in Pori (Luho 1954), are thus textiles. These nets are dated to ca. 1900 BC (Huurre 1998, 171–173) and have been made using 3-cabled linden strings (Luho 1954).

Not all textiles are made of flexible fibres, although the textile structure itself might allow bending or wrapping. For example, in Italy and Greece, stiff asbestos fibres were used as textile fibres in the 1<sup>st</sup> century AD to weave burial shrouds and make fire protecting garments (Forbes 1987, 63). Chainmails of iron ringlets were made to protect warriors during the Iron Age and the medieval period; today divers

protect themselves from shark bites by wearing chainmail made of stainless steel or titanium. Probably the plied metal wire used in yachts is on the border of being a textile, although in some cases, like in theatre or art, metal wire might be used in fantasy garments.

In many textile archaeological studies leather clothes, such as those of the Chalcolithic Ice Man Ötzi (Bazzanella 2012), are also seen as textiles at least if there is any stitching. It has been suggested that needle-like bone objects without an eye hole, found in Africa and made ca. 60 000 years BC, are in fact needles and used for piercing hides for sewing (Backwell et al. 2008). Bone needles with an eye hole suggest that sewing with yarns was already known in the Gravettian period (ca. 30 000–20 000 BC) (Soffer et al. 2000, 514). Indeed, simple furs might have been used as clothing for a very long period. The DNA of human body lice which live in cloth, differed from the head lice over 100 000 years ago, which suggests the constant wearing of clothes already that early (Kittler et al. 2003 and 2004).

An archaeological textile can be an inorganic pseudomorph, or be anticipated by the the other finds. For example, mammoth ivory beads in Upper Palaeolithic graves in Russia were probably sewn into leather garments, of which nothing is left (Soffer 1985, 456). In addition, Palaeolithic Venus figurines have incisions, which might indicate garments (Soffer et al. 2000). In Finland, possible leather garments are depicted in anthropomorphic clay idols from the Early Comb ceramic period 4200–3300 BC (Nuñez 1986). Their decoration suggests garments like ponchos, aprons, fringes and strings, resembling the ethnographic garments of Siberian shamans (Nuñez 1986, 25–26).

Of the several different possibilities for the phase for an archaeological textile presented above, the textiles studied in this dissertation are quite conventional. The examined textile finds are yarns from garments such as dresses, shawl cloaks and ribbons. However, due to degradation, the materials are no longer fully organic but are partly mineralised wool. This has had an effect on the selection of suitable analysis methods, since fragile and brittle finds cannot be analysed as soft and flexible i.e. by touching or stretching. In addition, everyday wear of textiles has caused fading of dyes and stained fabrics, which has an effect on the detected dye compounds and their degradation products. In an ideal world, it might be worth analysing the dark layers of organic materials of Late Iron Age burials to detect dyes, since this dark material might contain dye compounds although the textile itself is completely degraded.

## **2.2. Experimental archaeology**

Experimental archaeology sets up experiments to simulate the prehistoric processes in making and using artefacts, to understand the full manufacturing process, and to test interpretations made about archaeological finds (Coles 1979). This dissertation relies on experimental textile archaeology, which includes artefact and material studies and experimental research (Paper V; Andersson Strand 2010, 1–3). Accordingly, my study focuses on dyes and dyeing methods as a part of Finnish textile and dye history using the methods of natural science (HPLC, SEM-EDX), visual analysis, textile research and experimental archaeology. Experiments were applied to create reference data, to reconstruct dyeing processes and to test the behaviour of dyed yarns.

This study relies both on traditional, qualitative textile research and on empirical research, which means studying objects by making observations and quantitative measurements of the objects of interest. Quantitative data was acquired by the chromatographic analyses and standardised tests of the textile industry. This quantitative data was interpreted alongside of the qualitative data obtained by visual analysis, by element analysis using SEM-EDX, and by observing the selected basic parameters of the experiments.

Additional data was gained from previous textile archaeological research as well as from Finnish folklore surveys. This enabled an analysis of the similarities and dissimilarities between the Finnish archaeological material and the European material. As a result of this survey, a theory of local dye sources and dyeing methods was created. The hypothesis was tested with data produced by using textile industrial standards concerning the breaking strength the yarn as well as with experimental archaeology.

Natural sciences and textile industrial standards offer accurate results without a subjective influence. To get qualitative data from the dyeing, the fermentation experiments were documented by measuring the temperature and the pH value. Qualitative data was gained by observing bubbling, smell and the colour of the dye baths during the dyeing process (Paper V; Vajanto 2010; Vajanto 2013a). The fermentation experiments were made 3–5 times to deepen knowledge about the dye baths and to verify the reproducibility of the results. After gaining the quantitative and qualitative data a hypothesis was made to explain the data.

The results of experimental textile archaeology have been seen as an important basis for the interpretation of textile tools and the evolution of textile types, but it is also helpful in the visualisation of pre-historic material culture (Andersson Strand 2010, 2). However, it is sometimes difficult to know, when a result is achieved. In cases when the result is negative it is difficult to know whether the experiment went wrong, or whether the experiment succeeded but the result was not what was expected.

In Finland, experimental archaeology has often been seen as a part of history reenactment rather than a tool of scientific research, but associated. Despite these beliefs experimental archaeology is a valid tool for testing interpretations. For example, fragments of headdresses found in female burials in Western Finland and dated to the 11<sup>th</sup> and 12<sup>th</sup> centuries AD were first interpreted as *varsinaissuomalainen kaarihuntu*, i.e. *arc veil from Finland Proper* (Vahter 1952). Experimental archaeology revealed that this garment was unpractical in real life (Lehtosalo-Hilander 2001, 68; Riikonen 2006a, 26–27). More probable form of the headdress is conic, supported by outer bark of birch, and decorated with bronze rings surrounding head (Tomanterä 1984).

Experimental archaeology made in CTR in Denmark has produced good results concerning spinning and weaving (Andersson 1999; Andersson and Batzer 1999; Mårtensson et al. 2005). Preservation of dyes has been tested using experimental archaeology in Rørmyra near Trondheim in Norway and in Lejre in Denmark (Peacock 2004). In research connected to Hallstatt textiles, experimental archaeology has been applied not only to study spinning and weaving (Grömer 2005a and 2005b), but also to study prehistoric dyes and dyeing methods (Hartl and Hofmann-de Keijzer 2005; Hartl et al. 2015a, 2015b; Hofmann-de Keijzer et al. 2013a, 2013b). To describe more accurately this kind of research it was suggested that the term *experimental archaeology* could be changed to *empirical archaeology* (Paper V).

### 2.3. Ethnographic analogy

Ethnographic sources have played an important role in textile research, such as in studies concerning weaving (Hoffmann 1964). In Finland, there is knowledge is available for example on traditional spinning (Vallinheimo 1956), the cultivation of flax and hemp (Kaukonen 1946), nålbinding (Kaukonen 1960) and sheep shearing (Vuorela 1977). In this study, the unpublished survey data of the Finnish Literature Society (SKS) concerning traditional dyeing worked as a useful source for the dyeing experiments.

Ethnographic analogy can be a dangerous method for creating over obvious – and possibly wrong – interpretations. In my thesis, the ethnographic material from SKS was found to be incomplete when describing the actual dyeing methods. For example, the ethnographic data does not tell, *how* to dye red with for example with roots of common tormentil (*Potentilla erecta*). My first dyeings with this dye source produced only pale beige, because I had performed the dyeings by following the nowadays commonly used recipe – the boiling method with an alum mordant – which was apparently the wrong dyeing technique.

Ethnographic analogy can provide starting points in finding new insights into the researched material. For example, in my study, ethnographic data concerning the fermentation baths made of clubmosses (*Lycopodium* species) led to further experiments with archaic dyeing methods and finally to the fermentation of tannins (Paper V; Vajanto 2010; Vajanto 2013a). In the beginning, I had no idea how to prepare the fermentation baths from tree barks without mold growing. A clue came from the traditional manners to conserve fish from rotting and protect them from mold. That was done using wood ash lye – I presumed that this agent would similarly protect wool yarns and dye baths. Based on the survey data of SKS, the practical dyeing experiments and the results of chromatographic dye analyses, a theory of local dye sources and dyeing methods was created (Paper V).

## 3. Research materials

### 3.1. Archaeological samples

My dissertation focuses on 31 archaeological woollen samples from inhumation burials from Kaarina Kirkkomäki in Turku (10 samples), Rikala in Halikko (4 samples), Luistari in Eura (7 samples), Tuukkala in Mikkeli (5 samples), Yliskylä in Perniö (1 sample). These samples are in the collections of the National museum of Finland. In addition, textile fragments from two shipwrecks were included to my research. The finds from Lapuri (3 samples) and Egelskär (1 sample) and belong to the collections of the Maritime Museum of Finland. The research history, archaeological contexts, textile structures, wool types and dye results are discussed in Papers I, II, III and IV. (Fig. 2).

Every textile find was estimated to have a reddish shade of colour in visual analysis (Appendix 2). After visual and fibre analyses, tiny samples with a length of a few millimetres were cut and sent for (U)HPLC analyses to the Cultural Heritage Agency of the Netherlands (RCE) or to the Royal Institute for Cultural Heritage (KIK-IRPA) in Belgium, ie. to the laboratories that are specialised in dye analytics.

Before UHPLC analysis, Samples 9a, 9b, 10, 11a, 11b, 12, 13, 14, 15a, 15b from Kaarina Kirkkomäki had been analysed by Penelope Walton in the Anglo-Saxon laboratory in York by TLC (Paper I; Riikonen and Kirjavainen 2005 and 2007a; Walton 2001a and 2004a). TLC analysis detected a trace of alizarin, red tannins and indigotin (Walton 2001a, 2004a) in the analysed burial textiles from Kaarina Kirkkomäki, but no colourants such as Dyer's madder (*Rubia tinctorum*), kermes (*Kermes vermilio*), lichen orchil or weld (*Reseda luteola*). Because of these interesting TLC results, I wanted to get these finds reanalysed using new technology and uncover an explanation for the red tannins.

A reason for the limited number of archaeological samples is connected to the earlier methods of textile conservation. Decades ago fragile archaeological textile fragments were treated with Modocoll consolidant, which is a water-soluble polymer composed of ethylhydroxyethyl cellulose (EHEC) (Geijer



et al. 1961). This conserving medium was used to strengthen the brittle and fragile finds. But as years passed, the Modocoll formed a tight layer over the fibres, preventing chromatographic analyses. From the 1990s onwards, Modocoll has no longer been recommended in textile conservation (Peacock 1992, 204).

Several very interesting and clearly colourful textiles were discarded because of the Modocoll treatment, and left for future research hoping that someday a remedy for the Modocoll problem would be found. Especially dye analytic methods that are not based on chromatography, such as SERS (Surface-enhanced Raman spectroscopy) which is developing fast (Vanden Berghe 2013, 58), might be worth trying.

### 3.2. Reference dyeings

To find out the dye compounds of traditionally known local dye sources and mordants, 57 reference yarns were dyed (Appendix 5) with shrubs, leaves, tree barks, flowers, roots, cones, sprigs, mushrooms and lichens. In addition, I mordanted 3 references with alum, iron and copper mordant. The dyed yarns were analysed at the Cultural Heritage Agency of the Netherlands (RCE, 57 references) in Amsterdam and at the Royal Institute for Cultural Heritage (KIK-IRPA, 4 references) in Belgium with the same (U)HPLC method than the archaeological samples (Paper 1; Appendix 5). The woollen reference yarns were of Finnsheep, but some of Finnish Jaalasheep.

The aim of the references was to find dye compounds that match the compounds detected in the archaeological finds. Before my dyeings, the laboratories specialised in dye analytics had no references dyed with plants that grow in the Northern latitudes. Dye plants that grow in Central and Southern Europe are presumably different species than those used locally in Finland. I selected the dye plants for the reference dyeings according to the information given in historic documents, old dye books, and ethnographic and folkloric documentation. In addition, I analysed 11 archaeological samples and 12 reference samples with SEM-EDX in the Nanomicroscopy Center of Aalto University to detect mordants (Appendix 6).

I was highly conscious of the rarity of the species; and I also observed the regulations of the public right of access to the environment (Ministry of the Environment 2013). No growing places where dye plants were growing was picked bare and a good number of plants were left to grow and reproduce seeds. This careful attitude, and the fact that the collecting of lichens is only allowed with the landowner's permission, meant that the number of lichen-dyed references is small.

For certain particular dyeings I used well-known dyestuffs, namely tropical indigo (*Indigofera tinctoria*) and Dyer's madder (*Rubia tinctorum*); in these dyeings the aim was primarily to detect the used dyeing method (Appendix 5). The idea was that when using well-known dyestuffs any changes in the dye compound ratios would reveal an atypical dyeing method i.e. other than the boiling method with alum mordant.

### 3.3. Folklore sources and traditional dyeing

To find out the traditionally used dye plants, I collected data from old Finnish dyeing books and old literary sources. In addition I collected material from the Finnish Literature Society's Folklore archives (SKS/KRA), which survey data is unpublished, and represents the knowledge of practical handicrafts, beliefs, stories and the habits of local informants interviewed by students at the beginning of the 20<sup>th</sup> century (Papers I and V).

#### 3.3.1. Tannin dyes

Common tormentil (*Potentilla erecta*, Refs. 6 and 7) roots were traditionally used to dye wool yellowish red<sup>3</sup> and were sometimes mixed with roots of bedstraws<sup>4</sup> (*Galium* species, Refs. 2–5). Chewed common tormentil roots, barks of grey alder (*Alnus incana*), alder (*Alnus glutinosa*., Refs. 32 and 42) and birch (*Betula pendula*, Refs. 33 and 34) as well as branches of bear berry (*Arctostaphylos uva-ursi*, Ref. 10) were known as sources of red dye in 18<sup>th</sup> century AD Lapland, as described by Swedish botanist Carl von Linné (Itkonen-Kaila 1991, 6, 53, 78–79, 82). The same plants were mentioned in the first herbarium written in Finnish in 1866 by physician and linguist Elias Lönnrot, who interviewed ordinary Finnish folk to gain information about the useful properties of local plants (Linnilä et al. 2002). In addition to the previous plants, alder buckthorn (*Rhamnus frangula*, Refs. 25 and 37) and crowberry (*Empetrum nigrum*, Refs. 13 and 14) are mentioned as sources of red (Linnilä et al. 2002, III/129 and III/245).

Tannins were used in other Northern regions too, but especially in leather crafts. Red paint was prepared from barks of alder (*Alnus* species) and Siberian Larch (*Larix sibirica*) by the Siberian Mansi people to decorate leather items (Vahter 1953, 89). In 17<sup>th</sup> century AD Lapland Sami shamans painted figurines on shaman drums using boiled and mashed alder bark paint (Itkonen 1979, 119).

In Finland, as late as the early 20<sup>th</sup> century AD fibres were dyed with alder (*Alnus* species) bark although the early synthetic dyes were also available. According to folk sources, brown was obtained by boiling yarns with a copper coin and alder bark,<sup>5</sup> alder bark was used to darken the white cotton fishing nets,<sup>6</sup> and alder bark was used to dye wool red.<sup>7</sup> Fresh alder bark was boiled with yarn together with salt (NaCl) or copper mordant.<sup>8</sup> Alder bark dye was used likely because barks were available easily in forests and cost nothing.

In practice, the colour achieved with fermented tannins is reddish brown, not bright strawberry red. The red of folklore was not necessarily the same shade of colour that we consider to be red today. In Finnish the word for red *punainen* meant originally the colour of reddish animals. For example, the fox (*Vulpes vulpes*) was considered red, but nowadays its colour could be described as reddish brown (Toivonen et al. 1962, 640–641). Similarly, red beer was served at the weddings of Pohjola in *Kalevala* poem 20, probably meaning *reddish brown* beer (Kalevala 1949, 220).

3 SKS/KRA. Mannonen. 12 d, h, i, j, s: 4409. 1937.

4 SKS/KRA. Pärssinen. E 142: 14–16. 1938.

5 SKS/KRA. Laurila. E 138, 757:1. 1917.

6 SKS/KRA. Ollikainen. PK 24:4314. 1938.

7 SKS/KRA. Hörtsänä. 9:3058. 1953. SKS/KRA. Laitakari. b:481. 1936.

8 SKS/KRA. Pärssinen. E 142: 14–16. 1938.

### 3.3.2. Weeds from the fields and forests

The oldest list of Finnish dye plants was written in 1789, when economist Pehr Adrian Gadd was seeking new opportunities to utilise local nature resources. His list consisted of 33 plants and 4 lichens and some dyeing recipes. For example, gypsywort (*Lycopus europaeus*) and bearberry (*Arbutus Mjölonris* i.e. *Arctostaphylos uva-ursi*, Ref. 10) were sources of black, while dyer's chamomile (*Anthemis tinctoria*, Ref. 28), clubmosses (*Lycopodium* species, Refs. 46 and 47) and three-lobed beggarticks (*Bidens tripartita*) produced yellow dye. Woad (*Isatis tinctoria*, Refs. 23 and 24) and ash (*Fraxinus excelsior*) bark produced a blue colour, while alder buckthorn (*Rhamnus frangula*, Ref. 37) bark, common tormentil (*Potentilla erecta*, Refs. 6 and 7) and bedstraws (*Galium* species, Refs. 2–5) were used to dye red, and farns (*Tanacetum* species) and alder buckthorn (berries?) produced shades of green. (Gadd 1789).

According to SKS sources, strong yellow colours were dyed with heather (*Calluna vulgaris*, Refs. 11 and 12) and *other bog shrubs*<sup>9</sup> probably meaning bog rosemary (*Andromeda polifolia*, Ref. 9), crowberry (*Empetrum nigrum*, Refs. 13 and 14) and wild rosemary (*Rhododendron tomentosum*, Ref. 15). Bright yellow was dyed using birch leaves (*Betula pendula*, *Betula pubescens*, Refs. 17–19).<sup>10</sup> Lighter yellow shades came from stinging nettle (*Urtica dioica*), juniper sprigs (*Juniper communis*, Ref. 40) and cow parsley (*Anthriscus sylvestris*).<sup>11</sup>

Te Finnish dyeing books (Hellen 1919; Hassi 1978) include recipes for many other yellow yielding plants, such as leaves of lady's mantle (*Alchemilla vulgaris*, Ref. 16), rosebay willowherb (*Epilobium angustifolium*, Ref. 20), meadowsweet (*Filipendula ulmaria*, Ref. 21), hop (*Humulus lupulus*, Ref. 22) and alder buckthorn (*Rhamnus frangula*, Ref. 25). (Appendix 5.)

Bright red was dyed using roots of bedstraws (*Galium* species Refs. 2–5) roots.<sup>12</sup> Turquoise blue, or *ice coloured* yarns were dyed with fresh flowers of cornflower (*Centaurea cyanus*)<sup>13</sup> and heartsease (*Viola tricolor*, Ref. 31) (Linnilä et al. 2002, III/91–92; Vajanto 2013b). Berries of alder buckthorn (*Rhamnus frangula*) gave a blackish blue shade of colour.<sup>14</sup> Pure blue was dyed with three-weeks-old urine and “balls of blue” that were either tropical indigo (*Indigofera tinctoria*) or woad (*Isatis tinctoria*).<sup>15</sup>

### 3.3.3. Mordants

A traditional substitute for alum was prepared from local clubmosses such as fir clubmoss, (*Huperzia selago*, Ref. 46) and stiff clubmoss (*Lycopodium annotinum*, Ref. 47). All clubmoss species were used and the plant mordant was prepared by fermenting the bath.<sup>16</sup> Common chickweed (*Stellaria media*, Ref. 27) was occasionally used instead of clubmosses and used as fresh (Hellen, 1919, 19, Kontturi 1945, 13). Red sorrel (*Rumex acetosella*, Ref. 26) has been recommended as plant mordant when dyeing black (Kontturi 1945, 13; Hellen 1919, 20, 48–49).

9 SKS/KRA. Mannonen. 12 d, h, i, j, s: 4409. 1937.

10 SKS/KRA. Snellman. E 134:6–7. 1936; SKS/KRA; SKS/KRA. Pärssinen. E 142:14–16. 1938.

11 SKS/KRA. Laitakari. b:481. 1936; SKS/KRA. Onttonen. h 2431. 1936; SKS/KRA. Snellman. E 134:6–7. 1936; SKS/KRA. Pärssinen. E 142:14–16. 1938; SKS/KRA. Hörtsänä. 9:3058. 1953.

12 SKS/KRA. Pärssinen. E 142:14–16. 1938.

13 SKS/KRA. Salminen. E 177. 1947.

14 SKS/KRA. Mannonen. 12 d, h, i, j, s: 4409. 1937.

15 SKS/KRA. Tiitinen. 9.2985–3312. 1937.

16 SKS/KRA. Snellman. E 134:6–7. 1936.

Traditionally, wood horsetail (*Equisetum silvaticum*, Ref. 45) and field horsetail (*Equisetum arvense*, Ref. 44) were used for polishing household vessels (Linnilä et al. 2002, III/320), but also in dyeing pale yellow (Hellen 1919, 17). Eagle fern (*Pteridium aquilinum*, Ref. 48) has not been mentioned as a dye plant in Finnish folklore or in dye books. However, in Perth in Scotland eagle fern were presumably used as dye plants (Robinson 1987, 206–207). In Finland, ash made of burnt eagle fern was recommended for soap, while tea made of ferns was used to kill internal parasites (Linnilä et al. 2002, III/325). In addition, it was believed that ferns blossom on Midsummer night in places where there is hidden treasure (Sarmela 1994, 184).

*White alum* (aluminium sulphate, Refs. 58 and 61) was used as a mordant. Other mordants were obtained from black mud from bogs and springs or rusty nails (iron mordant, Ref. 60) and copper coins (copper mordant, Ref. 59).<sup>17</sup> Iron sulphate and copper sulphate were both called *vihtril*, which makes it difficult to know for sure what mordant was used in recipes.<sup>18</sup>

*Wine stone* i.e. cream of tartar i.e. potassium bitartrate ( $\text{KC}_4\text{H}_5\text{O}_6$ ) is not a mordant, but an additive often used in dyeing. It is not described in Finnish folklore recipes, but in dyeing books has been recommended to intensify the shades of red (Hassi 1978). *White* and *red* cream of tartar were used with alum (Hellen 1919, 9). In the European dyeing tradition cream of tartar has been used from the 14<sup>th</sup> century AD onwards (Chenciner 2000).

The ship *Vrouw Maria*, which sunk in the Archipelago Sea of Finland in 1771 on her way from Amsterdam to St. Petersburg, had a cargo consisting of cream of tartar, Dyer's madder (*Rubia tinctorum*), brazilwood (*Caesalpinia echinata*) and tropical indigo (*Indigofera tinctoria*) (Gelderblom 2003; Vajanto 2012). It is likely that cream of tartar was used especially by professional dyers rather than having anything to do with folk dyeing and the prehistoric Finnish dyeing tradition.

### 3.3.4. Lichens and mushrooms

In the 18<sup>th</sup> century AD Finland (then part of Sweden), peasants were encouraged to collect four species of lichens and sell them to suppliers to make a purple dye (Gadd 1789). Indeed, according to rumour, the Swedish peasants earned a barrel full of gold, just from collecting and selling lichens (Gadd 1789). The scientific names of these four lichen species mentioned by Gadd have changed over the centuries, but these might be rock tripe (*Lasallia pustulata*, Ref. 51), *Cladonia digitata* and crottle species (*Parmelia* and *Ochrolechia* species).

Lichen collecting was a common custom of the period, when large amounts of the *Ochrolechia* genus lichens were transported to Scotland to prepare a reddish-purple *cudbear* dye (Cardon 2007, 510–512). The orchil dyeing recipe is mentioned in a Swedish household book (Warg 1790) and a botanical book (Westring 1805). The recipe in Warg's book contains a recipe for wool dyeing with an orchil dye made in Sweden, obviously something similar to cudbear.

Crottle (*Parmelia saxatilis*, Ref. 52) was collected after rain, put into a cauldron with salt and boiled. Then cold water and fabric were added to the non-sieved dye bath and boiled; finally the fabric was washed, sometimes in a bath boiled of juniper sprigs.<sup>19</sup> The correct crottle species was bronze coloured

17 SKS/KRA. Laurila. E 138, 757:1. 1917; SKS/KRA Kotikoski. PK 11:2035. 1936; SKS Salminen. E 177. 1947.

18 SKS/KRA. Pärssinen. E 142:14–16. 1938.

19 SKS/KRA. Snellman. E 134:6–7. 1936.

at its base and grew on rocks and fences.<sup>20</sup> Some used crotle growing on birch bark.<sup>21</sup> Iceland moss (*Cetraria islandica*, Ref. 49) and star-tipped reindeer lichen (*Cladonia stellaris*, Ref. 50) were used to dye yellowish shades on wool (Hellen 1919; Hassi 1978).

Mushrooms are not traditionally known dye sources in Finland. However, they were included because mushrooms are common in Finnish forests and were probably available also during the prehistoric times. Two reference yarns were dyed with webcap mushrooms (*Cortinarius* species, Refs. 53 and 54). The *Cortinarius purpureus* reference was dyed by dyer Leena Riihelä, who was able to find these mushrooms.

### 3.3.5. Dyeing equipment

When dyeing with natural dyes, it is difficult to repeat exactly the same shade of colour in following dyeings. Thus big vessels (10–30 litres or bigger) are needed to dye whole fabrics or large amounts of yarns with identical colour. According to folklore, the best dyeing vessels were bronze cauldrons in which it was possible to dye all colours of the rainbow.<sup>22</sup>

Until the beginning of the 20<sup>th</sup> century AD, all kinds of smaller and bigger wooden vessels were common in household activities like brewing, baking, washing and tanning (Vuorela 1977). Blue was dyed in a wooden bucket in a warm sauna.<sup>23</sup>

Finnish ethnographic evidence contains a few tools particularly connected to dyeing. Specialized dyers used a so-called bedstraw hoe *matarakokka* to dig up narrow roots.<sup>24</sup> Another tool was the *flammekeppi* i.e. a wooden stick with indentations that permitted the dye penetrate yarns, while the other parts of skein were tightly tied onto stick to prevent dyeing (Vuorela 1977, 496–497). As a result, yarns became striped. These yarns were used especially as wefts and to create spotted weft-balanced fabrics. Alternatively, striped yarns were dyed just by tying the wool yarns tightly with cotton threads.<sup>25</sup>

Calico printing tablets, preserved occasionally in old manor houses, are connected to professional dyeing of the Early Modern period (Pylkkänen 1982, 59). Woad mills are absent in Finnish historical and prehistoric material. Woad (*Isatis tinctoria*) was never cultivated in Finland for professional dyers, although the landowners were occasionally encouraged to cultivate woad and build woad mills (Gadd 1760).

20 SKS/KRA. Snellman. E 134:6–7. 1936.

21 SKS/KRA. Pärssinen. E 142: 14–16. 1938.

22 SKS/KRA. Ollikainen. PK 24:9:4238–4525.

23 SKS/KRA. Tiitinen. 9.2985–3312. 1937.

24 SKS/KRA. Pärssinen. E 142:14–16. 1938.

25 SKS/KRA. Snellman. E 134:6–7. 1936; SKS/KRA. Pärssinen. E 142:14–16. 1938.

## 4. Analytical methods

### 4.1. Microscopic observation

Visual analysis is basic method in studying archaeological textiles. It gives information on the structures of textiles and is non-invasive. Visual analysis can be done simply with the bare eyes, or aided with a magnifying glass or using different types of microscopes. This kind of analysis and experimental archaeology was applied, for example, when reconstructing garments of Shetlandic Gunnister man from the early 18<sup>th</sup> century AD (Christiansen et al. 2013 and 2014).

Stereo microscopy can be used to obtain a good three-dimensional view of the analysed object. The courses of yarn can be followed to see how many times a yarn goes over and under each other. This can reveal whether the fragment has been woven or made with the nålbinding technique etc. or whether there is decoration, seems or stitches. Thread counts and yarn diameters etc. can be measured by a simple ruler at the side of the item or by a microscope software. (Papers I, II, III and IV).

Transmitted light microscope (TLM) enables to see the structures inside the fibrest, reveal the presence and form of the medulla in animal hairs that is important in identification on animal species. The fibres that lack scales, but have a vertical inner structure i.e. lumen, dislocations and cross-markings, indicate the possibility of plant fibres.

In sampling for TLM analysis, I cut small samples (1–2 millimetres) from the archaeological finds, placed them on objective slides with a drop of distilled water and covered it with a covering slide (Paper II, III and IV). For these electric fibres, distilled water worked better as medium than paraffin oil, which is often used in optical microscopy. Measurements were performed by the microscope's software. (Papers I, II, III and IV).

SEM imaging has been applied in studying small textile structures, especially in the pseudomorphic textiles, morphology of fibres, their degradation, contamination and mordants. Electrons have much smaller wavelengths, so remarkably smaller structures can be observed than using visible light. In combination, stereo microscopy, TLM and SEM give the best results when examining textiles, but require a good reference collection, practice and experience (Körber-Grohne 1988, 80) and often also cross sections of fibres (Goodway 1987). In the case of opaque fibres, i.e. pseudomorphic, heavily pigmented and charred fibres, SEM is more useful than TLM. While TLM analysis shows only a silhouette and the size, SEM can reveal morphological surface structures that are needed for the identification of the fibre (Gleba 2012, 3646 and 2013; Taub et al. 2012; Ryder and Gabra-Sanders 1985, 133–134).

When sampling for SEM analysis using JEOL JSM 7500 F, I cut 1-2-millimetre long fibres, placed them on a double sided carbon tape that was fixed on carbon stubs and coated them with 5 nanometres thick layer of carbon. Imaging was performed using SEI detectors, with an acceleration voltage of 5 kilovolt (kV) and an emission current of 10 microampere (µA).

### 4.2. Chromatographic analyses

The chromatographic dye analyses were performed using either High Performance Liquid Chromatography (HPLC) or Ultra High Performance Liquid Chromatography (UHPLC), both coupled to Photo Diode Array (PDA) detection system. There are several applications of HPLC analytics that differ from each other, for example, in the extraction solvent; in my study (U)HPLC refers both to HPLC and UHPLC.

The methodology of the analytics is explained in the Paper I. In general, only small samples such as 2–5 mm of yarn are required.

Most of the dye analyses were performed at the Cultural Heritage Agency of the Netherlands (RCE) under the supervision of Dr Maarten R. van Bommel (Proaño Gaibor 2011; van Bommel and Proaño Gaibor 2012; van Bommel and Joosten 2013; van Bommel 2014), while a minor group of samples was analysed at the Royal Institute for Cultural Heritage (KIK-IRPA) in Belgium by Dr Ina Vanden Berghe (Vanden Berghe 2012a, 2012b). (Papers I, II, III and IV; Appendices 3–5).

(U)HPLC can detect *dye-equivalents* that are compounds, in which the UV-Vis absorption spectrum corresponds to the spectrum of the reference dye, but the retention time ( $T_r$ ) differs. In the *dye-probably* compounds the retention time of the sample corresponds to the retention time of the references, but there is a poor match with the reference's UV-Vis absorption spectrum. In some cases, the colour of the unknown compounds can be deduced from the UV-Vis spectra; the problematic cases are the degradation products of dye compounds, which might differ from the original colour of the compounds.

The identification of dyestuffs is not always possible by (U)HPLC if the sample size is very small, the dyestuff concentration is very low, or proper reference material is not available. Accordingly, there can be completely unknown colourants that have no correlation to any natural dye or retention time, such as the unknown colourant 11 in Appendix 4. Fading, uneven dyeing, uneven preservation and contamination can cause error sources on the dye analyses (Hofmann-de Keijzer et al. 2013b, 137–139). Moreover, (U)HPLC is not sensitive to condensed (red) tannins, since these are big molecules, and do not pass the column of the device.

Thin Layer Chromatography (TLC) analysis is performed on a test plate i.e. stationary phase, on which the extracted sample has been dropped. The dye compounds move up on the plate in a solvent i.e. mobile phase via capillary action. TLC analysis is based on observing the order and colour of the eluted dye compound spots and comparing them to known references. There are several coating materials for test plates and different solvents for different dye groups (Hofenk de Graaff 2004).

TLC was applied to textile research from the 1980s onwards, but has been replaced nowadays by (U) HPLC applications because (U)HPLC has a better performance with a remarkably smaller sample size. The TLC analyses required large sample sizes, even several square centimetres. For example, the samples that had been analysed in Finland in 1972 by TLC had been very big: the smallest were 1x1 cm<sup>2</sup>, while the biggest were even 5x4 cm<sup>2</sup> (Wikström et al. 1972). TLC is still applied for example in lichen research (Stenroos et al. 2011).

### 4.3. Element analyses

To find mordants I performed element analysis on a selected group of samples. In Paper III, I presented element analyses that I had made on the Lapuri and Egelskär samples with pXRF device of Innov-x (alpha series). However, it became clear, that the pXRF was not suitable for the other samples, which were a lot smaller in size.

I selected SEM-EDX, i.e. scanning electron microscopy with an energy-dispersive X-ray spectrometer, as an alternative method to detect mordants on fibres. In the SEM-EDX the atoms of the sample are bombarded by the highly energetic electrons of an electron beam. In this process, electrons are knocked out of the inner atomic electron shells leaving these atoms in an excited state with empty places in their electron shells. The empty places in the inner atomic electron shells are then backfilled by electrons

from outer atomic electron shells. The electron transitions from outer to inner shells are accompanied by the emission X-rays that are characteristic for the individual atoms (Michler 2008, 105–107). Characteristic X-rays are detected by the energy-dispersive spectrometer and allow the identification of the chemical elements in the sample.

In SEM images the mordant salts appear as tiny particles on the surface of wool fibres (Frei et al. 2010). Element analysis has been carried out for example on the Hallstatt textiles to detect mordants but due to the contamination of the fibres by minerals from the mine it turned out to be impossible (Hofmann-de Keijzer et al. 2005 and 2013b). In Finland, same procedure has been done on burial textiles from Early Modern churches of the Northern Finland (Lipkin et al. 2015). The archaeological textiles are usually contaminated by the archaeological context, but the reference yarns are not, which makes the reference dyeings very important in this kind of research.

I performed the SEM-EDX analysis in the Nanomicroscopy Center of Aalto University in Espoo, Finland, using a JEOL JSM 7500F microscope. Altogether 15 archaeological samples were selected for element analysis. Most of these were left over material from UHPLC analysis; HPLC analysis had required slightly bigger sample sizes and thus only some left over samples were available. Shipwreck textiles were reanalysed to obtain comparison material to the burial finds concerning iron contamination from the archaeological context.

Archaeological textiles from burials might contain sand. Therefore a reference was very fine sand (Ref. 62). Other references were alum crystals, plant mordanted yarns and the yarns with alum, copper and iron mordant (Appendix 5, Refs. 26, 27, 44–48 and 58–62; Appendix 6).

The samples, i.e. 1–2 mm of fibre material, a few alum crystals and some sand, were placed on a double-sided carbon tape, placed on graphite stubs and were coated with 5 nanometres thick layer of carbon. SEM-EDX analysis was performed on area sized of 1–5 square micrometre ( $\mu\text{m}$ ) to include the mordant particles as whole in the measurement. The used acceleration voltage was 15 kilovolt (kV) and the emission current 10 microampere ( $\mu\text{A}$ ). Characteristic x-rays were collected for 30 seconds. The imaging was performed in a high vacuum of  $9.6 \times 10^{-5}$  Pascal (Pa) with the working distance of 8 mm. The EDX analysis was qualitative, since the measurements were performed on non-polished samples (Michler 2008, 107–111).

#### 4.4. Experimental archaeology

I made several experiments with dye baths, dyeing, mordanting and dyed yarns. The dyed yarns served as references for the archaeological samples. The (U)HPLC results of the references are presented in section 5.2.2, the dye experiments in section 5.3 and the element analyses in section 5.4.

First, altogether 39 of the 57 reference yarns were pre-mordanted by *boiling 100 grams of yarn for 1 hour with 12 grams of alum and 4 grams of cream of tartar* (Hassi 1978) (Appendix 5).

For dyes, the folklore sources recommended fresh plants, boiling them and finally sieving the dye bath; the yarns were washed beforehand, but not with soap in order to prevent an uneven dye.<sup>26</sup> I collected fully grown green leaves in spring, but some particular material in early summer, blossoming flowers and barks just before Midsummer, crotle during sunny summer days to get dry lichens, mushrooms in autumn, some shrubs in winter and bedstraw roots in early spring before the growing season. To get

26 SKS/KRA. Pärssinen. E 142: 14–16. 1938.

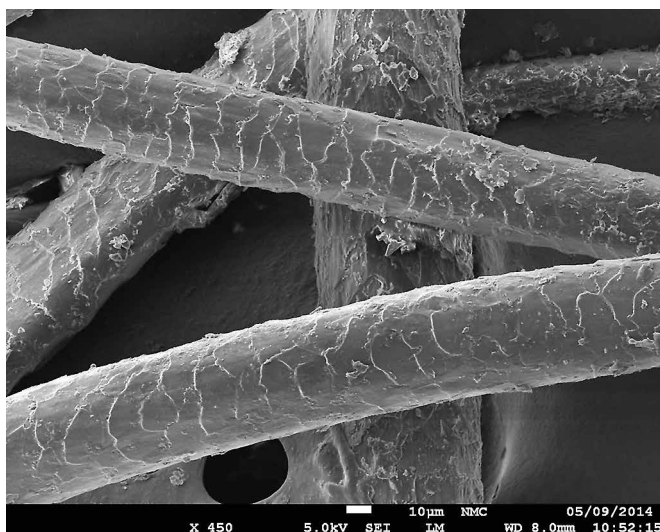


dyestuffs out of the plants, soft plants were boiled for one hour, but shrubs, cones and barks for three hours, after which the dye bath was sieved and cooled down.

In dyeing, the pre-mordanted yarns were added to the dye bath and boiled for one hour, after which the yarn was cooled down in the dye bath. Exceptions were fresh flowers (Refs. 28–31), bedstraw roots (*Galium* species, Refs. 2–5), which were boiled with the pre-mordanted yarns. Crottle (*Parmelia saxatilis*, Ref. 52) was boiled without any added mordants. The roots of common tormentil (*Potentilla erecta*, Ref. 7), crowberry shrub (*Empetrum nigrum*, Ref. 14), and alder buckthorn (*Rhamnus frangula*, Ref. 37) bark and silver birch (*Betula pendula*, Ref. 34) bark were fermented. ((Vajanto 2013b; Appendix 5).

(Fig. 18).

**Figure 18. Wool dyed with leaves of silver birch (*Betula pendula*, Ref. 18) and alum mordant; probable mordant particles apparent at fibre surface. (K. Vajanto, Nanomicroscopy Centre Aalto University).**



Woad (*Isatis tinctoria*) and Dyer's madder (*Rubia tinctorum*) have a well-documented dye composition (Schweppe 1993; Cardon 2007). These dyestuffs were used with different dyeing methods to find out, whether the (U)HPLC analysis could reveal the used dyeing method via the composition and ratio of the dye compounds. Accordingly, reference 8 was dyed in a fermented bath made of Dyer's madder; reference 56 was dyed with Dyer's madder and fermented fir clubmoss (*Huperzia selago*); reference 57 was dyed with Dyer's madder and fermented alder buckthorn (*Rhamnus frangula*) bark. Reference 23 was dyed with woad using fresh leaves, the boiling method and pre-mordanted yarn, while reference 24 was dyed in a vat made of fresh leaves, honey, wood ash lye and urine (Vajanto 2010). (Appendix 5).

The fermentation dye baths made of tannins and the orchil vat were fully experimental, since no accurate recipes were available. The pH value and temperature were measured with a pH device VWR International 100 once a day during a four-week test period. The bark baths, fermented with wood ash lye, gave qualitative data on the colour and smell changes of the baths (Vajanto 2010; Vajanto 2013a), as well as quantitative data concerning the changes in the pH-value and temperature. (Paper V).

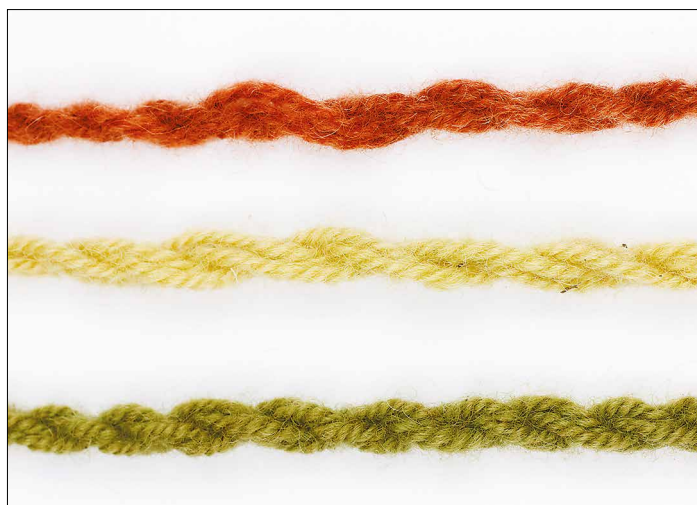
Plant mordants are often colourful and can also be used as dyes. Experiments were made by overdyeing plant mordanted yarns in an indigo vat to see the effect of the plant mordant in the final colour. The plant mordants were obtained from common chickweed (*Stellaria media*, Ref. 27), fir clubmoss

(*Huperzia selago*, Ref. 46), field horsetail (*Equisetum arvense*, Ref. 44), forest horsetail (*Equisetum silvaticum*, Ref. 45), eagle fern (*Pteridium aquilinum*, Ref. 48) and red sorrel (*Rumex acetosella*, Ref. 26). (Fig. 28)

One of the experiments was to test the breaking resistance of dyed and undyed yarns (ISO 2062:2009, ISO 1144:1973). The idea was to see how the different dyeing methods affect on the different wool. The examined material consisted of Finnish machine- and hand-spun woollen yarns. Based on the fibre analyses, which are presented in Paper IV, the selected wool types were as close as possible to Late Iron Age wool. I dyed the yarns with three different dyeing methods and three natural dyes i.e., mordant dyeing and boiling with Dyer's madder (*Rubia tinctorum*), the fermentation method alder buckthorn (*Rhamnus frangula*, Ref. 37) bark, and alkaline vat dyeing with rock tripe (*Lasallia pustulata*, Ref. 51). (Paper V).

It is commonly known that some colourants have poor light-fast properties and some are very light-fast. For example, excellent lightfastness values have been measured in the Hallstatt textiles (Hofmann-de Keijzer et al. 2013b, 159). In my experiments, new insight was sought for concerning the sustainability of the dyes. Colour fastness for perspiration (ISO 105-E04:2008, ISO 105-F01– F07:2009, ISO 105-A03:1993) was tested with 15 reference yarns dyed with various dye plants, flowers, barks and lichens. Aim was to test the sustainability of the traditional Finnish natural dyes and to compare the sustainability of dyes achieved with different dyeing methods. The mordant and vat dyes are often considered light-fast, but before this experiment no proper data was available on sustainability of anthocyanin dyes, fermented tannins and clubmoss mordanted dyes. (Paper V).

I made experiments to reconstruct old Finnish dyeing recipes concerning plant mordants. I collected species of clubmosses (*Lycopodium* species, Refs. 46 and 47) and succeeded to ferment the baths (Paper V). I also made experiments with horsetail species and found out that summer stems of wood horsetail (*Equisetum silvaticum*, Ref. 45) can dye wool a relatively strong salmon pink and eagle fern (*Pteridium aquilinum*, Ref. 48) dyed wool green – both without any added alum (Fig. 19). Thus the dye compounds as well as the element content were analysed not only in the clubmoss mordanted reference yarns, but also in the horsetail (*Equisetum* species) and eagle fern (*Pteridium aquilinum*) mordanted/dyed ones.



**Figure 19. Plant mordanted/dyed yarns. (J. Markkanen).**

**Top: forest horsetail (*Equisetum silvaticum*, Ref. 45) – reddish colour.**

**Middle: fir clubmoss (*Huperzia selago*, Ref. 46) – slightly yellowish.**

**Bottom: eagle fern (*Pteridium aquilinum*, Ref. 48) – green colour.**

## 5. Results of the analyses

### 5.1. Microscopy

The results of the microscopy analyses are presented in Papers I–IV. To summarise the results all the examined finds were woollen, predominantly from double-coated sheep. Warps were typically Sz-plied and wefts usually z-spun. The Luistari fragment KM 18 000:1702 was made using Sz-plied and s-pun yarns (Paper II), while the striped textile from Tuukkala KM 9770:5 (Samples 5a–c) was woven using z-spun and s-pun yarns (Paper I).

The even blue colour and the undyed parts in the yarns of Luistari grave 95 twills KM 18000:2071 and KM 18000:2084 (Samples 2a, 2b, 3a, 3b) indicate that these fabrics were dyed as a whole fabric (**Fig. 20**). The different shades of the yarns in the Rikala fragment KM 12690:168 (Samples 4a–d) suggest that the yarns were not dyed before spinning, but as yarns before weaving (**Fig. 21**). The fabric was possibly woven by two weavers which would explain the two different weft yarns (Vajanto and van Bommel 2014).



**Figure 20.** Undyed parts in the yarn from the Luistari grave 95 twill KM 18000:2071 (Samples 2a–2b). (J. Markkanen).



**Figure 21.** Textile fragment KM 12690:168 from Rikala (Samples 4a–d), woven with differently coloured bluish yarns. (K. Vajanto).

Most yarns in Kirkkomäki Samples and in the Yliskylä fragment KM 2912:53 (Sample 8) have an even colour, which suggest dyeing before plying, possibly even before spinning (**Fig. 22**). Stripes (**Fig. 23**) in the Tuukkala fabric KM 9770:5 (Samples 5a–c) and in the Luistari nålbinding fragments KM 18 000:1696 and KM 18 000:1702 indicate that the yarns were dyed before weaving and nålbinding (Papers I and II). Similarly, the shawl cloak of Kirkkomäki grave 1 was dyed before weaving (Samples 9a and 9b), since there are differently coloured yarns in warp and in weft. (Appendix 2).

Naturally pigmented, brown wool was found in the darning thread of the Lapuri find SMM 2592:8 (Sample 16c) (Appendix 2). An orange shade of colour was visible in a yarn from Tuukkala, KM 38090:682 (Sample 6) (Paper IV). This suggests contamination from the surrounding archaeological context or the

orange fibres might be tan, phaeomelanin-containing wool (Paper IV). Also in the Hammerun textiles found in Denmark there is quite a similar situation: no dyestuffs were detected in the HPLC analysis of the orange yarns, which were suggested to have a natural pigmentation of wool (Mannering and Ræder Knudsen 2013, 158).



Figure 22. Very even blue colour in the yarns from fragment KM 2912:53 (Sample 8). (J. Markkanen).



Figure 23. Striped half-basket weave and tabby found in the Tuukkala KM 9770:5 fragment (Samples 5a–c). (K. Vajanto).

## 5.2. Chromatography

### 5.2.1. Dyestuffs in the archaeological finds

The results of dye analysis of 31 archaeological samples are presented in Papers I, II, III and IV and in Appendices 3 and 4.

Purpurin, alizarin and possible xanthopurpurin were detected in the Samples 1a–1c from Luistari, suggesting local bedstraws (*Galium* species). The opposite ratio, i.e. more alizarin than purpurin, suggests the use of Dyer's madder (*Rubia tinctorum*). This was found in the probably imported textile found in Tuukkala (Samples 5a and 5c).

Several unknown anthraquinones-probably were detected (Spectra 4, 5, 6, 7, 12, 29, 30 and 33). For example, the weft yarn of the Kaarina Kirkkomäki shawl cloak from grave 1 (Sample 9a) contained the anthraquinone-probably (Spectrum 12), which was labelled as unknown-red-468 (Tr 16.11 min/ 468.9 nm) (Vajanto and van Bommel 2014). This same anthraquinone-probably was detected in three Early Modern textile fragments from Oulu Cathedral (Lipkin et al. 2015).

Sample 5c from the tabby area of the three-coloured Tuukkala fragment contained the flavonoids apigenin and luteolin referring to weld (*Reseda luteola*), saw-wort (*Serratula tinctoria*), Dyer's broom (*Genista tinctoria*) or other species containing these compounds. Possible chrysoeriol, that is a luteolin-equivalent, was detected in the Samples 2a, 2b, 3a, 3b from Luistari (Paper I, Appendix 3). This colourant occurs as minor component in the European dye plants in which apigenin and luteolin are abundant. However, because neither apigenin nor luteolin was detected, an interpretation was not possible (Paper I).

Several unknown flavonoids-probably (Spectra 2, 3, 8, 9, 10, 15, 20, 26 and 31) appeared (Samples 2a, 2b, 3a, 3b, 4a, 4b, 4c, 8, 10, 12, 14 and 16b). The Spectrum 1 had absorbance at 278 and 309 nm and was detected in Samples 2a, 2b, 3a, 3b, 4a, 4b, 4c, 5a, 5b. This compound is possibly a maclurin-equivalent (Paper I).

An unknown reddish compound, Spectrum 23, was found in six samples from Kirkkomäki (Samples 10, 11a, 11b, 12, 13 and 14). Also other unknown reddish colourants occurred: Spectra 18 and 21 (Sample 8), Spectrum 34 (Samples 11a and 11b), and Spectra 35–37 (Sample 13).

Indigotin or its trace was detected 17 samples, indirubin or its traces in 11 samples, isatin or its traces in 12 samples and isatin-equivalent in one sample. Woad flavonoid was found in two samples (Samples 1c and 4a). A red compound, Spectrum 19, possibly woad red, was detected in two samples (Samples 11a and 11b). Indigoid dyestuffs were often detected with reddish, orange or yellow dyestuffs, most of these being unknown colourants.

Lichen orchil-probably, Spectrum 13, was found in the weft yarn (Sample 9b) of the Kaarina Kirkkomäki shawl cloak from grave 1 (Vajanto and van Bommel 2014). The red and blue lichen-related compounds in Spectra 13, 14, 16, 17 formed sharp peaks in the UV-Vis spectrum and were comparable to the reference dyed with rock tripe (*Lasallia pustulata*, Ref. 51), although degradation of the dyestuffs occurred (Vajanto and van Bommel 2014; van Bommel 2014).

In addition, the Spectrum 13 occurred in the Kaarina Kirkkomäki Samples 10, 11b, 12 and in the Sample 8 from Yliskylä. Samples 8, 11a, 11b, 15b shared a sharp-formed compound i.e. Spectrum 27. The sharp-formed Spectra 11 and 24 (Samples 9a, 11a and 11b), suggest lichen compounds. Diamond green and unknown synthetic red (Spectrum 22), were detected in Sample 15b (Paper I).

Altogether 7 samples were possibly undyed. Of these, the samples from Lapuri shipwreck (Samples 16a–16c) contained ellagic acid. No organic colourants were detected in the Egelskär fragment (Sample 17) (Vanden Berghe 2012a; Paper III). Also the Sample 5b from Tuukkala was probably undyed (Paper I). The detection limit of the HPLC could explain the negative results in the small Samples 6 and 7 found in Tuukkala grave 11. For very small samples, such as the Sample 5a which contained ca. 100–200 single fibres, the newly developed UHPLC method seems to be a better tool of analysis.

The detected unknown colourants of the Finnish finds are not the same that have been detected, for example, in the Hallstatt textiles (Hofmann-de Keijzer et al., 2005a; Hofmann-de Keijzer et al., 2013a), in Lønne Hede and Hammerun textiles found in Denmark (Demant 2007, 88; Vanden Berghe et al. 2009) or in the textiles of Thorsberg found in Germany (Vanden Berghe and Möller-Wiering 2013). The (U)HPLC spectra made with different solvents and different devices are not directly comparable, but these results might be useful starting points for future studies and for international discussion.

### 5.2.2. Dyestuffs in the reference yarns

The most relevant dye compounds detected in the references detected by (U)HPLC analysis are presented in Appendix 5.

The only detected hydrolyzable tannin was ellagic acid, which was found as the main compound in the yarn dyed with cones of alder (*Alnus glutinosa*, Ref. 42). Aside from various flavonoids, ellagic acid was present in yarns dyed with roots of purple marshlocks (*Comarum palustre*, Ref. 1), roots common tormentil (*Potentilla erecta*, Refs. 6 and 7), leaves of rosebay willowherb (*Epilobium angustifolium*, Ref. 20),

leaves of meadowsweet (*Filipendula ulmaria*, Ref. 21) and bark of rowan (*Sorbus aucuparia* Ref. 39), just to name a few.

Catechin belongs to the group of condensed tannins (proanthocyanidins) that are present in various plant species – such as alder (*Alnus* species), alder buckthorn (*Rhamnus frangula*), willow (*Salix* species) eagle fern (*Pteridium aquilinum*) and heather (*Calluna vulgaris*) (Cardon 2007; Schweppe 1993). Catechin equivalent was found in the reference dyed with silver birch bark (*Betula pendula*, Ref. 33). Unknown red compounds, possibly related to condensed tannin compounds, were in the references 11, 13, 14, 33, 35, 36, 38, 39, 40, 42, 43 (Proaño-Gaibor 2011).

Anthraquinones were detected in the references dyed with roots of Northern bedstraw (*Galium boreale*, Ref. 2), white bedstraw (*Galium album*, Ref. 3), common marsh bedstraw (*Galium palustre* var. *balticum*, Ref. 4) and Lady's bedstraw (*Galium verum*, Ref. 5). These contained purpurin as a main compound. Alizarin, rubiadin, nordamnacanthal and unknown compounds were also detected. The reference dyed with fresh leaves of alder buckthorn (*Rhamnus frangula*, Ref. 25), and the one dyed with the bark of this same plant (Ref. 37), contained emodin and chrysophanic acid. Emodin and dermocybin were the main colourants of the yarn dyed with fermented surprise webcap (*Cortinarius semisanquineus*, Ref. 54). Unknown anthraquinones as well as dermocybin were found in the yarn dyed with another webcap mushroom (*Cortinarius purpureus*, Ref. 53).

Most of the detected compounds were flavonoids, like quercetin, rutin, kaempferol, luteolin and apigenin as well as their equivalents. These flavonoids give wool yellow colour. But as similar compound combinations are present in references dyed with so many different dye plants, these flavonoids are not good markers for any of these dye plants. Unexpectedly, apigenin, luteolin and genistin were found in the reference dyed with fresh lupine (*Lupinus polyphyllus*) flowers (Ref. 29). Usually these are considered as markers of Dyer's broom (*Genista tinctoria*) (Schweppe 1993).

Maclurin and maclurin-equivalents are the benzophenone class of dyes (Cardon 2007). These were found in three references, the ones dyed with red sorrel (*Rumex acetosella*, Ref. 26), fir clubmoss (*Huperzia selago*, Ref. 46) and eagle fern (*Pteridium aquilinum*, ref. 48). Several unknown compounds were present in the references dyed with Iceland moss (*Cetraria islandica*, Ref. 49) and star-tipped reindeer lichen (*Cladonia stellaris*, Ref. 50).

Only indigotin was found in the yarn dyed with fermented bark of silver birch (*Betula pendula*) and tropical indigo (*Indigofera tinctoria*) – tannin compounds were not detected at all (Ref. 55). Orcein, unknown lichen reds and unknown lichen blues were found in the reference dyed with rock tripe (*Lasallia pustulata*, Ref. 51). Crottle (*Parmelia saxatilis*, Ref. 52) contained unknown yellow compounds and compounds showing absorbance only at the UV-area of the spectrum.

### 5.3. Dye experiments

The results of the tenacity tests are described in Paper V. To summarise, the strongest yarns of this test were undyed or dyed with the fermented alder buckthorn bark (*Rhamnus frangula*) bath, which produced a red yarn that retained the original strength, or even increased it. The effect of the dyeing method was strongest in the yarns spun of primitive kind of wool that contained both underwool and outer coat hairs. Dyeing with the fermented tannins makes the wool fibres look as if they are “glued” (Fig. 24), which can be connected to the penetration of tannins between the wool's scales.



Those yarns that were dyed for the tenacity test using rock tripe (*Lasallia pustulata*) vat suffered less than one would assume. It is known, that the alkaline dye bath removes lanolin from wool, cuts wool's peptide bonds, shrinks the fibre and eventually destroys it (Landi 1987, 12–15). This action was visible in reference fibres that were dyed in urine vats. The alkaline vats opened the surface scales and “polished” fibres (Fig. 25). However, dyeing with rock tripe was performed in an alkaline bath, but at a temperature of +4°C, which presumably protected the wool from heavy degrading. This dyeing method was less harmful to some wool types than the commonly favoured boiling method. Fading of achieved shade of colour in sunlight was rapid (Fig. 27). (Paper V).

The yarns with the weakest tenacity were the ones that were dyed using alum mordant, the boiling method and Dyer's madder (*Rubia tinctorum*). Wool has good tolerance towards acidic baths, which have no effect on the wool protein's sulphur bonds and only some effect on the peptide bonds. However, long heating can break of sulphur and peptide bonds (Tímár-Balázs and Eastop 1998). The damaged fibres with opened scales detected in the yarn dyed with Dyer's madder (*Rubia tinctorum*) are probably caused by the boiling method (Fig. 26). (Paper V).

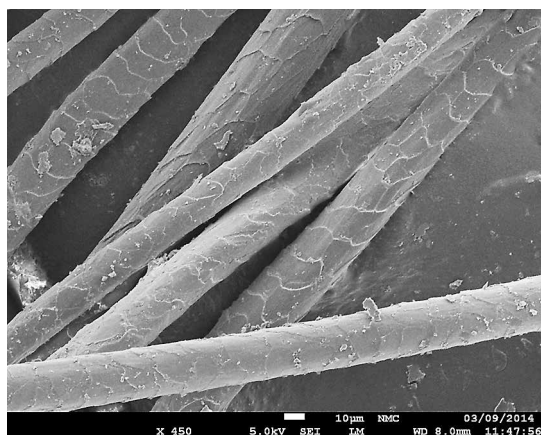


Figure 24. Wool fibres with “glued” scales in yarn dyed with alder buckthorn (*Rhamnus frangula*, Ref. 37) in a fermentation bath. (K. Vajanto, Nanomicroscopy Centre Aalto University.)

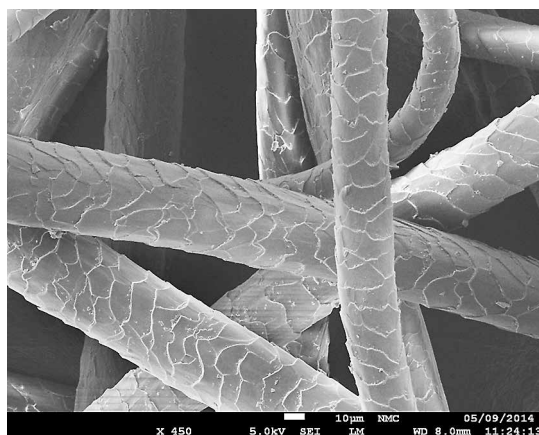


Figure 25. Wool fibres with “polished” scales in yarn dyed with rock tripe (*Lasallia pustulata*, Ref. 51) in urine bath. (K. Vajanto, Nanomicroscopy Centre Aalto University.)

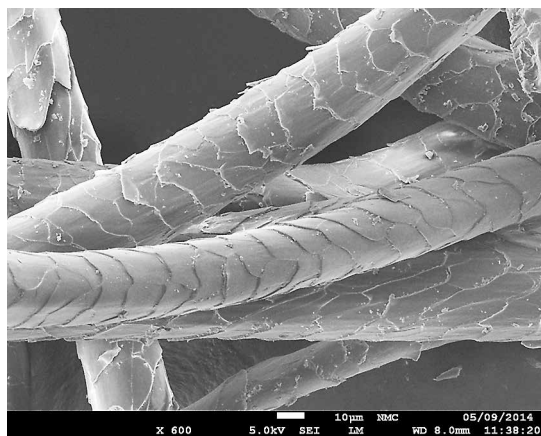


Figure 26. Alum mordanted and boiled yarn dyed with the Dyer's madder (*Rubia tinctorum*); opened scales visible. (K. Vajanto, Nanomicroscopy Centre Aalto University.)

The colour fastness in perspiration test resulted in excellent or good sustainability in all the analysed dyeings. Even the turquoise yarn dyed with flowers of lupine (*Lupinus polyphyllus*) received good scores, although these contain anthocyanin dyes. Reference yarns dyed with mordant dyes and alum were not superior to the references dyed with other dyeing methods. For example, the reference dyed using fermented clubmoss (*Lycopodium* species) bath and Dyer's madder (*Rubia tinctorum*) got excellent values with minimum amount of fading (Ref. 56). Same phenomenon was with the reference dyed with the fermented alder buckthorn (*Rhamnus frangula*, Ref. 37) bark. (Paper V)

The experiments with tannin baths are discussed in Paper V. To summarise, the pH values of the tannin baths were highly alkaline at first, but decreased in a few days to neutral and then to acidic. During that process the smell of the alder buckthorn (*Rhamnus frangula*) bath also changed, and begun to smell like red wine, except the silver birch (*Betula pendula*) bath, which smelled and looked like blood. In the rock tripe (*Lasallia pustulata*) vat the pH remained highly alkaline all the time, but the wool remained relatively soft, presumably because of the cold dyeing conditions. The clubmoss (*Lycopodium* species) bath smelled like lemon juice, and became sour, what is an ideal pH value for the wool dyeing.



**Figure 27. A yarn dyed with rock tripe (*Lasallia pustulata*, Ref. 51). (J. Markkanen).**

**Colour fastness of rock tripe (*Lasallia pustulata*, Ref. 51) dyed yarn was tested by keeping the yarn on a sunny window.**

**On the left = non-faded dye**

**In the centre = moderately faded dye (2 weeks in sunlight)**

**On the right = strongly faded (2 months in sunlight).**

Wool yarns that were mordanted with plant mordants and over dyed in an indigo vat produced new colours. The reference yarns was blue and the yarns dyed using common chickweed (*Stellaria media*) and fir clubmoss (*Huperzia selago*) mordant were quite close to the reference's shade of blue. Mordanting with forest horsetail (*Equisetum silvaticum*) resulted in a blackish blue hue. Eagle fern (*Pteridium aquilinum*) mordanted gave a dark turquoise blue, field horsetail (*Equisetum arvense*) resulted in a dark emerald green and red sorrel (*Rumex acetosella*) mordanted a dark grass green. (**Fig. 28**)





Figure 28. Wool yarns mordanted/dyed with plant mordants and tropical indigo (*Indigofera tinctoria*).

(J. Markkanen). From top to bottom:

Blue = no mordant

Blue = Common chickweed (*Stellaria media*)

Slightly greenish blue = Fir clubmoss (*Huperzia selago*)

Blackish blue = Forest horsetail (*Equisetum silvaticum*)

Dark turquoise blue = Eagle fern (*Pteridium aquilinum*)

Dark emerald green = Field horsetail (*Equisetum arvense*)

Dark grass green = Red sorrel (*Rumex acetosella*)

## 5.4. Elements

Results of the element analysis are presented in Appendix 6.

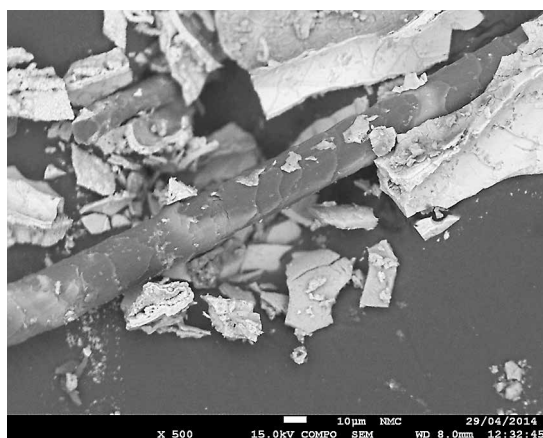
Carbon (C), oxygen (O) and sulphur (S) were detected in each fibre sample (Appendix 6). These are typical elements of wool (Tímár-Balázs and Eastop 1998), but carbon and oxygen are also connected with sample preparation. The reference dyed with crottle (*Parmelia saxatilis*, Ref. 52) contained no added mordant and accordingly, the fibre surface was very clean.

The SEM-EDX analysis detected aluminium (Al), sulphur (S) and potassium (K) in alum crystals ( $KAl(SO_4)_2 \cdot 12H_2O$ ) (Ref. 61). Aluminium (Al) without any potassium (K) was detected in the alum mordanted reference (Ref. 58). This alum mordant was visible randomly on the fibre surface as small particles. Copper (Cu) was found in the copper sulphate,  $CuSO_4 \cdot 5H_2O$ , mordanted reference (Ref. 59). No iron was detected in the reference mordanted with iron sulphate  $FeSO_4$  (Ref. 60). Sand contained only silicon (Si) (Ref. 62).

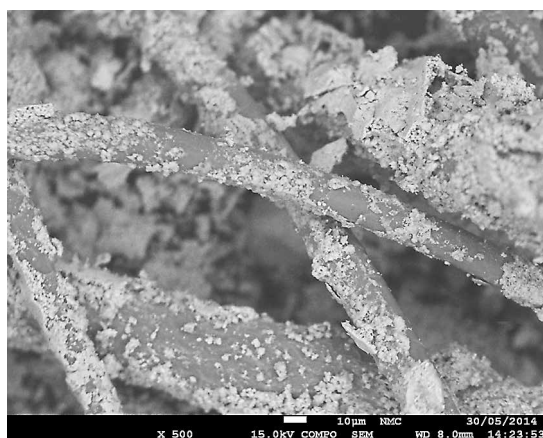
The wool fibres mordanted with stiff clubmoss (*Lycopodium annotinum*, Ref. 47) and fir clubmoss (*Huperzia selago*, Ref. 46), had particles all over the fibre surface. These particles contained aluminium (Al), silicon (Si) and potassium (K) (Vajanto and van Bommel 2014; Fig. 32). Field horsetail (*Equisetum arvense*, Ref. 44) and forest horsetail (*Equisetum silvaticum*, Ref. 45) contained a similar element combination (Al+Si+K). The references mordanted with common chickweed (*Stellaria media*, Ref. 27), red sorrel (*Rumex acetosella*, Ref. 26) and eagle fern (*Pteridium aquilinum*, Ref. 48) contained potassium (K). Of these yarns, the highest potassium content was found in the eagle fern mordanted reference.

The red yarn from Luistari n lbinding textile (Sample 1b) was loosely covered by particles that contained aluminium (Al), potassium (K) and silicon (Si). Also the Sample 8 from Yliskyl  and the Kirkkom ki Samples 9a, 9b, 10, 11a, 11b, 12, 13, 14, 15a, 15b contained aluminium, often with potassium (K) and/or silicon (Si).

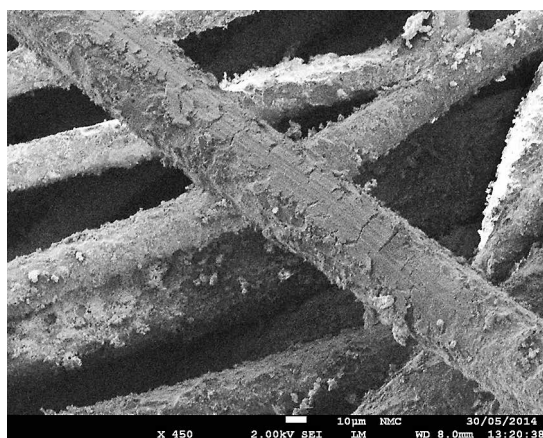
Other detected elements were iron (Fe), copper (Cu) and magnesium (Mg). In Samples 1b, 8, 11a, 11b, 12 and 13 the particles were randomly distributed, while in Samples 9a, 9b, 10, 15a, 15b a layer covered the fibres. In Sample 14 the fibres were preserved inside a layer of phosphor (P) and iron (Fe) (**Fig. 29**). The Lapuri and Egelsk r shipwreck samples contained iron (Fe) and calcium (Ca) (Samples 16a, 16b and 17). (**Fig. 30 and Fig. 31**).



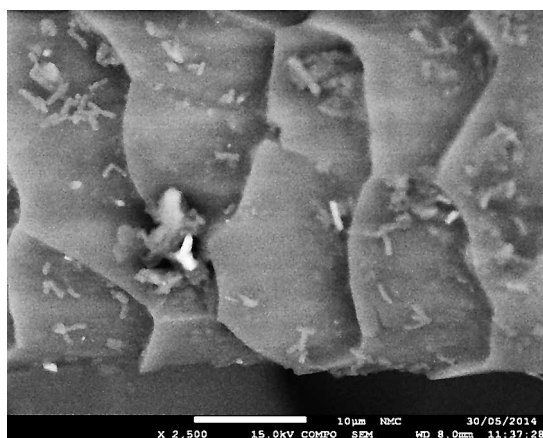
**Figure 29.** Fibres of Kaarina Kirkkom ki find KM 27025:H27:237 (Sample 14) preserved inside a layer of iron (Fe) and phosphor (P). (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 30.** Fibres covered with iron (Fe) and calcium (Ca), in the fragment SMM 1657, 342006:16 (Sample 17) from Egelsk r. (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 31.** Fibres heavily covered with iron (Fe), in a fragment from Lapuri SMM 2592:8 (Sample 16a). (K. Vajanto, Nanomicroscopy Centre Aalto University).



**Figure 32.** Stiff clubmoss (*Lycopodium annotinum*, Ref. 47) mordanted wool fibre. Aluminium (Al), silicon (Si) and potassium (K) particles are visible all over the fibre surface. (K. Vajanto, Nanomicroscopy Centre Aalto University).

## 6. Discussion of colourants, mordants and dyeing methods

### 6.1. Fermented tannins

It has been suggested that the red tannins detected by TLC in Kaarina Kirkkomäki Samples 9a, 10, 11a, 12, 13, 15a originate on alder bark (*Alnus glutinosa*) (Walton 2001a; Walton 2004). The interpretation of the TLC analysis was based on the reference dyed with young alder twigs (Walton 2001a). The match was not perfect, but however, it was possible to exclude anthraquinones of kermes (*Kermes vermilio*), Dyer's madder (*Rubia tinctorum*) and bedstraws (*Galium* species) as well as lichen purple (Walton, 2001a). In addition, red tannin dye was detected in one textile from medieval Turku (Walton 2001b).

In other TC analyses a tannin dye was detected in warp and weft yarns of the apron as well as in the warp of the dress in found in Tuukkala grave 26 in Mikkeli (Walton 2004a). This time, it was possible to exclude flavonoids of weld (*Reseda luteola*), Dyer's broom (*Genista tinctoria*) and alder buckthorn (*Rhamnus frangula*) (Walton 2004a); possibly referring to the berries or leaves of alder buckthorn, since bark contains emodin, chrysophanic acid and tannins (Appendix 5).

Red tannin has been detected by TLC in textiles found in Lønne Hede, Denmark, dated to the 1<sup>st</sup>–2<sup>nd</sup> century AD (Walton 1988a; Walton Rogers, 1997; Demant 2007, 86). Also, a trace of tannin was detected in the visually red yarns in the textiles from the Lønne Hede grave 2, but its source remained unidentified (Demant 2007, 88; Walton 1997). No dyes were detected by HPLC in the red Lønne Hede yarns (Vanden Bergh 2013), which also was the case with the several reddish yarns of the Thorsberg textiles (Möller-Wiering 2012; Vanden Berghe and Möller-Wiering 2013). This suggests a dye or dyeing method that cannot be detected by (U)HPLC as well as a local northern provenance (Vanden Berghe and Möller-Wiering 2013).

Presumably the red tannins detected by TLC appeared as unknown colorants in UHPLC analysis (Paper I; Appendix 4). Especially the Spectrum 23 could be connected to the red tannins detected by the TLC analysis (Paper I). This orange compound was detected altogether in six samples from Kaarina Kirkkomäki grave 27 i.e. in Samples 10, 11a, 11b, 12, 13, 14 (Appendix 4).

It is known that (U)HPLC is not sensitive detecting to detect the big molecules of condensed tannins (Paper I). Quite clearly this can be seen in reference dyeings in which condensed tannins are absent (Appendix 5). This suggests that the Spectrum 23 and the many other unknown colourants could be, for example, degradation products of condensed tannins (Appendices 3 and 4). However, without a match with the references this question remains unsolved – Spectrum 23 could also be a degradation product of anthraquinones or lichen dyes.

Fermentation baths of tree barks and roots of common tormentil (*Potentilla erecta*) need no boiling. This might be the case with other other tannin-rich plant materials too, like *Rumex* species. In practice, plant materials can be fermented in wooden vessels, which can be warmed up for example with heated stones. The easy dyeing technique and the evidence of the folklore suggest that the fermented baths were used in dyeing during the Finnish Late Iron Age (Paper V; Vajanto 2010; Vajanto 2013a).

Dyeing with the fermentation method is time consuming, although it does not need constant active work from a dyer. Dyeing with different dyestuffs and over-dyeing needs perfect skills as well as careful

organizing and accurate timing. In other words, the darker the aimed shade of colour, the longer the dyeing usually lasts. This increases the value and appreciation of the dyed textiles, which might have happened in the Late Iron Age Finland too.

TLC detected red tannins and a trace of alizarin in Sample 13 (Walton 2001a; Kirjavainen and Riikonen 2007, 135–137), while UHPLC found an unknown yellow and red-orange (Paper I; Appendix 4). This suggests the use of tannin mordant for anthraquinones (Vajanto 2013a) in Sample 13. Probably in Samples 13 and 14 the original shade of colour has probably been reddish, but in the other samples the shade of colour has been darker due to double dyeing performed with indigoids and lichen orchil.

The Spectrum 23 often appears with possible lichen compounds, suggesting either double dyeing or that these both might originate from one and the same dye bath. Two gallic acid molecules form ellagic acid (Schweppe 1993, 472), which is present in many shrubs, trees and nut shells with condensed tannins (Cardon 2007, 425). Gallic acid, which is a part of hydrolysable tannins, and its polymers, gallotannins, can be found in many plants such as gallnuts and bear-berry (*Arctostaphylos uva-ursi*) (Cardon 2007, 693). Again, gallic acid is a relative of depsides and depsidones. The depsides are present especially in lichens (Schweppe 1993, 469), while depsides and depsidones which are relatives of orchil are found in lichens (Schweppe 1993, 469, 520–523; Cardon 2007, 703–704). An enzyme, *tannase*, is able to hydrolyse both gallotannins and depsides (Haslam and Stangroom, 1965; Cardon 2007, 693; Treviño-Cueto et al. 2007).

The role of tannase might have been useful in dye baths made of barks and lichens. Chewed, macerated (soaked and fermented) and finally boiled alder bark was used by the Navaho Indians to dye red, sometimes together with lichens of the *Xanthoparmelia* species (Cardon 2007, 426). In the 18<sup>th</sup> century France it was suggested that a pre-mordant bath made of birch bark might improve the sustainability of lichen orchil dye (Cardon 2007, 494). Lichens often grow on tree bark so they could be part of a bark bath simply by accident, or they might have been added to the dye bath intentionally. My experiments with tree barks and roots of common tormentil (*Potentilla erecta*) have been very slow processes (Paper V). With new experiments it could be possible to shed light on the possibility that lichens somehow catalyse the fermentation baths made of barks and common tormentil roots. Concerning the Finnish archaeological finds, one possibility is that both barks and lichens gave the red colour to the yarns.

In Finnish folklore, tannin baths and blood were associated (Toivonen et al. 1958, 288). In the old Finnish language the word for blood *veri* was a taboo word and therefore the name for alder tree *leppä* was used instead (Toivonen et al. 1958, 288). This is understandable, since the fermented tannin baths such as those prepared of alder buckthorn (*Rhamnus frangula*, Ref 37) bark, silver birch (*Betula pendula*, Ref. 34) bark and roots of common tormentil (*Potentilla erecta*, Ref. 7) look like blood (Paper V).

Because tannin baths and blood were often associated, it is no wonder that the roots of purple marshlocks (*Comarum palustre*, Ref. 1) were used both in dyeing wool (Linnilä et al. 2002, III/183), but also to treat menstruation problems (Paulaharju 1908). Also common tormentil (*Potentilla erecta*, Refs. 6 and 7) was used in dyeing, tanning, and in treating dysentery (Linnilä et al. 2002/III, 327). In Lapland, tannin dye represented bear's (*Ursus arctos*) blood: after a successful hunt the women chewed alder bark and prepared red paint, which was spurted on the men's faces during the hunting feast. The aim was to make the men look heroic, as smeared with the bear's blood (Itkonen 1979, 201–202).

A rapid change from yellow to red occurs when the yarn is lifted from the blood-looking dye bath (Vajanto 2010; Vajanto) – which might have been seen as a good starting point for beliefs. Crafts like weaving and spinning create order from disordered basic materials, such as fibres and yarns into a finished product, and have been associated with life and fertility (Davidson 1998; Scheid and Svenbro 2001; Heide 2006). Possibly dyeing too included these same aspects (Rammo and Maatsin 2014). For example, it was not allowed to dye during menstruation, since during that time a woman was “in colours herself” which would lead to piebald yarns (Talvela 2013, 80). Unfortunately, the Late Iron Age beliefs and rituals are hard to prove by means of archaeology.

There has been a practical reason to use the fermented tannins in dyeing red yarns and black as well through the double dyeing technique. Fermented tannins do in fact strengthen the wool yarns (Paper V). Accordingly, During the Iron Age, fabrics were woven in warp-weighted looms which needed good tenacity from the warp yarns. I suggest that in Late Iron Age Finland the aim was not only to obtain red yarns, but also to dye strong yarns.

## 6.2. Red anthraquinones

Anthraquinones of *Rubiaceae* were rare in the researched material. Only one local textile contained purpurin, alizarin and xanthopurpurin. This was the nålbund textile from Luistari (Samples 1a–1c) (Paper II). The ratios of these compounds suggest local bedstraws such as Northern bedstraw (*Galium boreale*, Ref. 1), white bedstraw (*Galium album*, Ref. 2) and Lady's bedstraw (*Galium verum*, Ref. 4). In addition, unknown anthraquinones were detected, suggesting a local dyeing method or degraded anthraquinones (Appendix 3, Spectra 6 and 7, Paper II).

Sample 1a was visually yellow, but contained purpurin as main colourant, and also alizarin, indirubin and indigotin. No yellow dyestuffs were found (Van Bommel and Joosten 2013). Despite the detected compounds, it was suggested that the yellowish yarn had originally been undyed – the colourants being contamination from the red and blue stripes. Alternatively, the yellowish yarn might have been dyed in an exhausted dye bath. (Paper II).

Closest parallels for the Finnish bedstraw dyes have been detected in the Siksälä textiles found in Estonia, dated to the 12<sup>th</sup>–15<sup>th</sup> centuries AD (Rammo and Maatsin 2014). These yarns were spun of brown wool and dyed using local Northern bedstraws, although Dyer's madder (*Rubia tinctorum*) was available in the urban centres nearby (Rammo and Maatsin 2014).

Dyer's madder was found in the striped textile fragment from Tuukkala cemetery (Samples 5a and 5c; Appendices 2 and 3), suggesting an imported textile (Paper I). However, the ratio of alizarin and purpurin did not correspond perfectly Dyer's madder, so there also might have been bedstraws in the dye bath or a special dyeing technique (Paper I). The two unknown anthraquinones (Spectra 4 and 5, Appendix 3) might indicate local dyeing methods and local dye sources, but also be degradation products of dyestuffs. The unknown colourant, that might be a maclurin-equivalent (Spectrum 1), suggest the use of plant mordant (Appendices 3 and 5).

In many European languages, bedstraws have names similar to the English word *madder*, which is also the case with the Finnish word *matara* (Paper I). This can indicate the predominant role of Dyer's madder in the European dyeing tradition and people's empirical understanding of the similar dyeing properties of other plants of the *Rubiaceae* family (Cardon 2007, 128). In Finland, Dyer's madder and bedstraw dyes seem to be connected to international influences, and especially to the improved availability of

alum. Especially the Hanseatic League imported fabrics and dyes to the Northern regions of Europe. As result of this trade, several textiles with Dyer's madder and/or bedstraw colourants have been found in medieval Turku (Kirjavainen 2002; Kirjavainen and Riikonen 2007a, 2007b).

The weft yarn of the Kaarina Kirkkomäki shawl cloak from grave 1 contained not only lichen dyes, unknown reds and indigotin, but also an unknown anthraquinone (Spectrum 12, Appendix 4) (Paper I). The detected anthraquinone-probably eluted at retention time 16.10 min at an absorption maximum of 468 nm (Appendix 4). The same anthraquinone-probably was found in three Early Modern samples from Oulu Cathedral (Vajanto and van Bommel 2014; Lipkin et al. 2015). Neither the retention time nor the absorption maximum matched with any known anthraquinone, which suggest local dyes and/or local dyeing methods. In addition, Sample 9b also contained two anthraquinones-probably (Spectra 29 and 30). The dye combination suggests that the aim was to dye dark purple yarns. Due to indigotin, lichen orchil, tannin and an anthraquinone dye, this purplish shade of colour achieved was strong and intensive.

Degraded insect anthraquinones might appear in the Finnish finds too. Kermesic acid has been detected in the 10<sup>th</sup>–15<sup>th</sup> century AD textiles found in Novgorod in Russia (Nahlik 1963; Kublo 2012, 254). In the 9<sup>th</sup> century Norway, Dyer's madder, kermes dye (*Kermes vermilio*) and indigotin have been detected in the textiles from the Oseberg burial (Ingstad 2006, 191–192; Vedeler 2014, 51). Polish cochineal (*Porphyrophora polonica*) was in the 5<sup>th</sup>–6<sup>th</sup> century AD textiles from Veien, Norway (Walton 1988a, 148, 156; Halvorsen 2013), while the textiles from Evebø/Eide contained Polish cochineal or kermes dye (Walton 1988a, 150). Insect and plant anthraquinones, indigotin, apigenin and luteolin have been detected in the 5<sup>th</sup> century AD Högom burial in Sweden (Nockert 1991, 72–75; Hofenk de Graaff 2004, 109–110).

The Baltic Sea connects distant shores, which enables the transport of Polish cochineal via maritime routes. River routes from the Black Sea to the North were used by the Vikings (Larsson 1991, 11–27). Oriental and Byzantine silver coins in Finland and Scandinavia are evidence of this eastern traffic (Talvio 2002). According to a saga, exotic kermes dye was probably in the of clothes of the 11th-century warrior Bolli Bollason who, returned from his journey wearing scarlet clothes given to him by the Emperor of Constantinople (Zanchi 2008, 22–23, 31). If textiles were imported to the North, perhaps also insect dyestuffs or wild madder (*Rubia peregrina*), which contains several anthraquinones, anthrogallol and lawsone (Cardon 2007, 123; Wouters 2001).

TLC analysis detected a trace of alizarin in the braided leg wrap band (Sample 13; Appendix 1) found in the Kaarina Kirkkomäki grave 27 (Walton 2001a), but UHPLC analysis found three unknown reddish colourants i.e. Spectra 35, 36 and 37 in the same yarn (Appendix 4). These reddish colourants might be degraded anthraquinones, or degraded lichen dyestuffs or degraded tannins. In future experiments, aged and cold treated references would presumably bring new data concerning the unknown red colourants in the archaeological finds by breaking dye compounds into their degradation products.

### 6.3. Yellow flavonoids

The imported, three-coloured textile found in Tuukkala in Mikkeli (Sample 5c) contained apigenin and luteolin in two yarns. These compounds refer to weld (*Reseda luteola*), Dyer's broom (*Genista tinctoria*) and saw-wort (*Serratula tinctoria*), which were common dye plants in the medieval world. In Central Europe, yellow was dyed using the boiling method and alum mordant (Cardon 2007).

Possible maclurin-equivalent was detected in Tuukkala Samples 5a–c. Maclurin and maclurin-equivalents were also detected in the three plant mordanted references (Appendix 5, Refs. 26, 46 and 48). It is unclear, whether the maclurin-equivalent was originally used in dyeing both the red and yellow yarns of the Tuukkala fabric. Dyestuffs can leak out from the fibres and contaminate other yarns nearby. It is possible, that the maclurin-equivalent belonged originally to the anthraquinones-dyed yarn 5a, and the detected anthraquinones in the yarn 5c might then be contamination from the red yarns.

Possible flavonoids were detected in Samples 2a, 2b 3a, 3b, 4b, 4c, 4d, 8, 10, 12, 14 and 16b (Spectra 2, 3, 8, 9, 10, 15, 20, 26 and 31). Spectra 8, 9, 10, 26 and 31 appeared only once, but the Spectrum 15 appeared twice. Sample 14 contained three flavonoids-probably i.e. Spectra 8, 10, 26 (Appendix 4). Because no correlation with the references was found, the flavonoids-probably could originate from unknown local dye sources or indicate local dyeing techniques, or be degradation products of dyestuffs. The Spectra 2 and 3 might be woad flavonoids and are discussed in section 6.5.1.

One possibility is that the detected unknown flavonoids are contamination from the environment. For example, it has been suggested that the colourless or yellowish unknown compounds might be connected to the buried corpse (Vanden Berghe et al. 2009, 1918). The role of the flavonoid compounds could be estimated taking samples from the archaeological context and the surrounding soil for (U)HPLC analysis. Careful sampling would also help to understand dyeing properties of the burial items such as the wooden coffins, the plants that grow at the site, the colourants of autumn leaves, as well as the furs and moss below or top of the deceased. In Denmark, this kind of study was carried out to estimate the dyeing properties of bog water and bog plants in the textiles of bog bodies – and here the colourants of textiles were interpreted as dyes, not as contamination (Vanden Berghe et al. 2009).

Yellow flavonoids, such as apigenin, luteolin, kaempferol, rutin and quercetin are the most commonly detected dyestuffs in the references dyed with the Finnish yellow yielding dye plants (Appendix 5). The absence of these yellow flavonoid dyes in the archaeological samples is distinct. One possibility is that these dyestuffs have degraded completely (Paper I). Alternatively, these dyes were never used in the burial textiles during the Late Iron Age. It is possible that the medieval influences directed the upper class women to select other dyes for their textiles, such as fermented tannins, lichen dyes and woad colourants. Perhaps flavonoid dyes were used to dye everyday garments or the clothes of persons of lower social status.

Apigenin and luteolin are rare findings also in the other prehistoric textiles in the North. The skirt of the Huldremose woman, dated Early Roman Iron Age was dyed with woad and luteolin with an unknown yellow-orange compound (Vanden Berghe et al. 2009 and 2010; Mannering et al. 2010, 266). Also several other Danish Early Roman Iron Age textiles contained luteolin (Vanden Berghe et al. 2009 and 2010). In Sweden, flavonoids of weld (*Reseda luteola*), anthraquinones suggesting Dyer's madder/bedstraw and Polish cochineal along with and indigotin have been detected in Högom textiles (5<sup>th</sup> century AD) (Nockert 1991, 73–75; Hofenk de Graaff 2004, 109–110).

In Finland, in a medieval textile fragment which possibly was a dress of Virgin Mary's statue, apigenin, luteolin and indigotin were detected in one yarn system, while Dyer's madder was found in the other (Kirjavainen 2012). Quercetin, luteolin, flavonoids and possible datiscin of bastard hemp (*Datsica cannabina*) have been reported in the medieval textiles from Novgorod (Kublo 2012, 254–255). There are weld-dyed textile fragments also from the medieval Tartto (Rammo 2015).

There is ethnographic and folklore evidence of the utilisation of the many yellow dye sources available in the Finnish nature (Appendix 5). The use of yellow flavonoid dyes in Finland might reflect international

influences, especially the dye history of Central Europe and the Hanseatic trade that presumably increased alum trade and the availability of weld (*Reseda luteola*) dyed fabrics. A similar case is with Dyer's madder and bedstraw dyes, which have been found in medieval Turku more frequently than in Late Iron Age textiles (Kirjavainen and Riikonen 2005; Kirjavainen and Riikonen 2007a).

## 6.4. Mordants

It is difficult to identify mordants from the contamination of the archaeological context. Possibly the detected lighter elements such as phosphor (P), magnesium (Mg) and calcium (Ca) are accumulation from bones and environment. The amount of metal mordant used in prehistory is not known, but it is known that too much metal mordant makes wool yarn coarse and brittle. The recommended amounts of iron mordant and copper mordant is 2–8% of the yarn's weight, for alum 10–15% (Hassi 1978; Tetri 2008, 43–45). This suggests that large amounts of metal elements in fibres likely indicate contamination from the archaeological context.

SEM-EDX revealed a thick layer of iron (Fe) and calcium (Ca) in the shipwreck textiles from Lapuri and Egelskär (Samples 16 a–c, 17). These elements are probably not connected to the role of iron as a mordant (Paper III). The Egelskär fibres had a thick iron covering all over the surface, while the Lapuri fibres looked as if they were painted, suggesting a different formation process of the covering layer. In Lapuri Samples 16a and 16b, the thick layer of iron on the fibres was interpreted to originate from red ochre. This suggests so-called *smörning* treatment made on the sail (Paper III), a process where red ochre was mixed with horse, beef and mutton tallow, tar and fish oil (Bender Jørgensen 2005, 66; Cooke and Christiansen 2005, 71).

Alum ( $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ ) and copper sulphate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) sulphate appeared in the references as very small particles that were distributed randomly on the fibre surfaces (Refs. 58 and 59). Iron sulphate ( $\text{FeSO}_4$ ) was not detected on fibres (Ref. 60), suggesting wrong observation settings or very fine mordant particles under the detection limit. In Samples 10, 11b, 14 and 15b iron (Fe) was detected, but as big particles not resembling those of the references. For example, Sample 14 was preserved inside an iron and phosphor (P) layer. This suggests a pseudomorph formed of vivianite (**Fig. 29**). Vivianite is blue mineral, formed in natural processes in soil around buried bones. As inorganic colorant, it does not stick on wool fibres and can not be used as blue dye.

Plants often contain condensed tannins with hydrolysable tannins, which with iron produce black. Ellagic acid and iron were detected in the Lapuri Samples 16a–16c (Vanden Berghe 2012a), but these findings were interpreted as contamination (Appendix 2; Paper III). Amongst the red tannin-containing Samples 9a, 10, 11a, 12, 13, 15a iron was detected only in Sample 10. The absence of hydrolysable tannins and iron being detected in only one sample suggests that iron mordant was not systematically used to produce black with tannins. Presumably iron is contamination from burial objects, such as iron nails and iron knives.

Copper (Cu) was detected in almost every sample found in burials, but with a bigger particle size than in the references (Appendix 6). So, copper is probably contamination from bronze spirals, jewellery and bronze knives. The archaeological iron and bronze cauldrons are small and rare finds (Kivikoski 1973, Tables 113 and 144) so they were unlikely dyeing vessels. Ceramic vessels leak no mordants and can stand boiling, but large-sized vessels are not known in Finnish Late Iron Age material. However, the detected copper contamination might have had some mordanting effect on textiles after burial, since without copper, the organic material including textiles and dyes would not have been survived. (**Fig. 33**)



**Figure 33. Spirals bordering a replica of a Late Iron Age apron. (M. Pasanen).**



SEM-EDX analysis detected aluminium (Al), potassium (K) and silicon (Si) in references mordanted with stiff clubmoss (*Lycopodium annotinum*, Ref. 47), fir clubmoss (*Huperzia selago*, Ref. 46), field horsetail (*Equisetum arvense*, Ref. 44) and forest horsetail (*Equisetum silvaticum*, Ref. 45). These elements appeared as particles with a size of 1–5  $\mu\text{m}$ . These formed a randomly distributed layer all over the fibre surface. This element combination (Al+K+Si) had similarities with alum crystals (Ref. 61) in which SEM-EDX detected aluminium (Al), potassium (K) and sulphur (S). Silicon (Si) was detected in the reference made of fine sand (Ref. 62), which suggests that sole silicon would indicate sand contamination.

The element combination found in the plant mordanted references (Al+Si+K) was also detected in Samples 1b, 8, 11a, 11b, 12 and 14. The archaeological fibres were covered randomly with particles sized 1–5  $\mu\text{m}$  (Appendix 6). These samples also contained anthraquinones, anthraquinones-probably and flavonoids-probably. Based on these parameters, plant alum was possibly in these samples. In archaeological textiles element contamination from burial environment is always possible, but the presence of anthraquinones and flavonoids i.e. mordant dyes suggests intentional use of plant mordant.

There might be differences in the aluminium content of clubmoss species, of which fir clubmoss (*Huperzia selago*) has been reported to have the less amount of aluminium (Hartl et al. 2015a). Macrofossil remains of Northern running-pine (*Lycopodium complanatum*) were excavated in Anglo-Scandinavian (Viking Age) York with macrofossil remains of weld (*Reseda luteola*) and Dyer's broom (*Genista tinctoria*) (Hall and Thomlinson 1989; Walton and Hall 1997, 1768). That clubmoss species is not a native in England, but was imported by the Vikings for its good mordanting properties (Hall and Thomlinson 1989; Cardon 2007, 34). According to ethnographic evidence, all available clubmoss species were utilized in Finland, which was possibly the case also during the Late Iron Age.

Common chickweed (*Stellaria media*, Ref. 27), eagle fern (*Pteridium aquilinum*, Ref. 48) and red sorrel (*Rumex acetosella*, Ref. 26) contained potassium (K). These plants could have been used somehow to improve the achieved shade of colour. Potassium-containing cream of tartar has been used for the same purpose, especially to increase the intensity of red colours (Hassi 1987). According to traditional recipes, potassium-containing common chickweed has been used for example to dye black with

logwood (*Haematoxylum campechianum*) (Christensen 1932, 37). In practice, logwood, alum and cream of tartar produce violet shade of colour on wool (Hassi 1978), while logwood and common chickweed with no mordant produce copper brown. When dyeing clubmoss (*Lycopodium* species) mordanted yarns with logwood and common chickweed (*Stellaria media*), the result is black. (Fig. 34).



**Figure 34. Yarns dyed with logwood (*Haematoxylum campechianum*) with different mordants (J. Markkanen).**  
**From top to bottom:**  
**Violet = alum and cream of tartar**  
**Dark copper = common chickweed (*Stellaria media*)**  
**Black = clubmoss (*Lycopodium* species) and common chickweed (*Stellaria media*) mordants**

The references mordanted with fir clubmoss (*Huperzia selago*, Ref. 46), red sorrel (*Rumex acetosella*, Ref. 26) and eagle fern (*Pteridium aquilinum*, Ref. 48) contained flavonoids, maclurin and maclurin-equivalents (Appendix 5). A maclurin-equivalent was detected in Samples 2a, 2b, 3a, 3b, 4a–4d, 5a–5c (Paper I, Appendix 3). This suggests that in archaeological textiles maclurin and maclurin-equivalent might originate from plant mordants. With indigoid dyes, plant mordants provide new shades of colours and intensify shades of blue (Fig. 28).

Maclurin-equivalents have also been detected in the Bronze and Iron Age Hallstatt textiles, in yellow, green, olive green and brown yarns (Hofmann-de Keijzer et al. 2013a, 126–127; Hofmann-de Keijzer et al. 2013b, 154, 160–161). Purple gromwell (*Buglossoides purpureoacerulea*) has been suggested as source of this compound (Hofmann-de Keijzer et al. 2013b, 153–154). However, this plant is not native to Finland, so the plant mordants i.e. red sorrel, eagle fern and fir clubmoss are more probable sources for maclurin and maclurin equivalents.

## 6.5. Woad colorants

### 6.5.1. Woad flavonoids

Indigotin, indirubin and isatan were the most frequently detected dyestuff in the research material (Appendices 3 and 4, Paper I). A woad flavonoid was detected in Samples 1c and 4a (Paper I; Appendix 3). In addition, a red compound possibly related to woad was detected in Samples 11a and 11b (Appendix 4,

Spectrum 19, Paper I). Woad flavonoids together with blue pigment indigotin suggest woad (*Isatis tinctoria*) as source of blue colour in Finnish Late Iron Age textiles, not tropical indigo shrub (*Indigofera tinctoria*).

Samples 2a, 2b, 3a and 3b from Luistari contained possible chrysoeriol, which is a luteolin-equivalent and occurs as a minor component in the dye plants, in which apigenin and luteolin are abundant (Paper I). This luteolin-equivalent was detected at a retention time  $T_r$  17.07 min and its spectrum shows an absorption maximum at 348 nm. This is close to the compound W349 with retention time  $T_r$  16.596 min, detected in the references prepared during woad dyeing experiments in Austria (Hartl et al. 2015b, 22, 29). Possibly the identified chrysoeriol (Paper I) is a woad flavonoid.

In the experiments made in Austria, yarns dyed with couched or fresh woad leaves contained not only indigoids, but also woad flavonoids. These woad flavonoids were not present in yarns dyed with woad pigment (Hartl et al. 2015b, 25, 28). This suggests that Samples 2a, 2b, 3a, 3b (Appendix 3) also were dyed using fresh or couched woad leaves.

Samples 2a, 2b, 2a, 3b, 4b, 4c, 4d also contained possible maclurin-equivalent (Appendix 3; Paper I). This suggests the use of mordant dyes. Possibly these Samples were dyed twice, which would explain their dye compositions. A possibility is dyeing with woad leaves using the boiling method, which dyes wool salmon pink (Appendix 5). This is supported by the fact that the reference 23 contained a woad flavonoid, other flavonoids, unknown reddish-orange compounds and very small amounts of indigoids (Appendix 5). Woad flavonoids and indigoids in the archaeological samples could thus indicate not only vat dyeing, but also mordant dyeing.

For example, perhaps the yarns were first plant mordanted to obtain aluminium, silicon and potassium, maclurin and maclurin-equivalents, then boiled with fresh woad leaves get unknown reddish-orange compounds, woad flavonoids and even small amounts of indigotin and indirubin which should be formed only in a vat. Then the yarns possibly were dyed in a fermentation vat, to obtain indigotin, indirubin, isatin, more woad flavonoids and woad red. Altogether, the plant mordant bath and double dyeing resulted in a blackish-blue hue on wool, as well as various greenish-blue shades depending on the concentrations of the mordant and dye baths (Fig. 28).

### 6.5.2 Indigoids for blue and black

Sky blue was probably not the original shade of colour of the analysed indigotin-containing samples. Indeed, all these samples also contained dyestuffs that had absorbance at reddish, orange and yellowish wavelengths. For example, probably Samples 2a, 2b, 3a, 3b from Luistari were originally blackish, dark brownish or dark greenish. Sample 8 from Yliskylä contained such a high amount of indigotin with many unknown reddish components (Appendices 2 and 4) that the original colour of this textile must have been nearly black.

In the Icelandic medieval sagas blue and black (dyed using blue) textiles were amongst the most valuable textiles - only fabrics with scarlet red and golden colours were more expensive (Straubhaar 2005, 65). Dark blue shawl cloaks were possibly highly valued garments that were worn on special occasions and indicated a high position in society (Riikonen 2006b, 377–378). Status garments with a cloak were used also by the high rank women in Scandinavia during the Late Iron Age (Krag 2005). In Finland, dark blue shawl cloaks were still worn in the 14<sup>th</sup> century AD Tuukkala, indicating a long-lasting fashion. Possibly they were highly appreciated ritual garments and/or a means to indicate own ethnicity.

Similar kind of situation has been found in Siksälä in Estonia, where blue shawl cloaks, for example, were still made in Iron Age style during the Middle Ages (Rammo and Maatsin 2006, 286).

The Kaarina Kirkkomäki material suggests that there has been a certain fashion in men's and women's clothes. Accordingly, more red dye was found in men's garments (Riikonen 2006b), while women's garments were more often contained indigotin (Riikonen 2006b, 377–378; Kirjavainen and Riikonen 2007a and 2007b). Textile finds from the settlements would probably bring interesting new data concerning Late Iron Age fashion and favourite colours.

Based on the textile research concerning the Viking Age finds, it has been suggested that blue was the colour of death (Walton 1988b; Straubhaar 2005). Unfortunately, this is impossible to prove with the archaeological means. In practice, dyeing with indigoids is impressive: the yarns in a leuco-indigo vat are pale yellowish and turn rapidly greenish and finally blue when lifted from the vat. This change of colour might have given starting points for beliefs, about changes in life from childhood to old age, and the transition from life to death. The changing of colours could be seen symbolising women's fertility (Rammo and Matsin 2015). If this was the case in Finland too, it is understandable, why the craft to dye dark fabrics with indigoids vanished during the spread of Christianity.

Woad (*Isatis tinctoria*) is a rare plant that grows on sandy shores on the southern and western coasts of Finland (Paper I). In southern regions of Europe, for example in France and Germany, woad was cultivated from the 13th century AD onwards (Balfour-Paul 2011, 32–33), but no ethnographic evidence of cultivating woad exists in Finland nor in Estonia (Peets 1998). Even the Finnish name for woad, *morsinko* or *morsiuskruunu* i.e. “bride's crown” was created at the end of the 19th century AD by the physician and linguist Elias Lönnrot to describe the yellow blossoming plant. Indeed, this wild weed was noticed by a scholar first time in the 18th century AD, when even cultivation instructions were written (Gadd 1760 and 1789).

Late Iron Age woad dyeing craft has possibly been a rare skill, performed by a limited amount of dyers. This might explain the absence of ethnographic evidence concerning woad plant and woad cultivation. The common Northern plants such as Devil's-bit (*Succisa pratensis*), water knotweed (*Polygonum amphibium*), meadowsweet (*Filipendula ulmaria*) and cow parsley (*Anthriscus sylvestris*) contain precursors of indigotin, but in such low concentrations that they were unlikely to be used in blue dyeing (Aittomäki et al. 2000, 99–101; Pečeliūnaitė-Bazienė 2010). This suggests that possibly woad balls were traded to Late Iron Age Finland – this import needs no local cultivation. A woad seed has been found in the 3<sup>rd</sup>–5<sup>th</sup>-century Ketohaka settlement in Salo (Aalto 1982), suggesting a non-intentional spreading amongst seeds of crops – or perhaps inside the imported woad balls.

The problem concerning the availability of blue pigment is also found in Estonia (Peets 1998; Rammo and Matsin 2015) and in Lithuania, where the archaeological material contains several blue textile finds, but woad is very rare (Pečeliūnaitė-Bazienė 2010). Blue textiles were dyed in Novgorod at the second half of the 12<sup>th</sup> century AD, but the source of blue is not mentioned in the local historical sources (Kublo 2012, 450).

It has been suggested that during the Viking Age, tropical indigo (*Indigofera tinctoria*) was traded by the Vikings to Estonia (Peets 1998). Tropical indigo pigment is an ideal trade product: it is insoluble in water and even withstands wetting. The tropical indigo pigment from the 1641 wrecked *Nuestra Señora de la Concepción*, for example, was still able to dye textiles blue in experiments (Cowan and Balfour-Paul 2011). Unfortunately, the chemical composition and structure of indigo pigment is identical in all indigo-yielding plants and its origin from a particular plant is not determinable.

In future, perhaps the rapidly improving strontium analytics would be able to shed more light on the provenance question concerning indigotin and other dyes (Frei et al. 2009 and 2010). However, based on the woad flavonoids of the analysed archaeological samples, the source of blue in Late Iron Age Finland was most probably woad (*Isatis tinctoria*), but the use of tropical indigo (*Indigofera tinctoria*) cannot be excluded completely.

## 6.6. Lichen purple

The unknown red and blue compounds with a sharp peak in the spectra are presumably hydrolysed compounds of lichen orchil (Appendix 4; Vajanto and van Bommel 2014). Lichen orchil dyed textiles fade soon in direct sunlight (Paper V; Cardon 2007, 485–492) (**Fig. 27**). However, when tested with ISO 105-E04: 2008 textile standard, the rock tripe dyed yarn received excellent values in the perspiration test and caused no staining (Paper V). If worn only occasionally in special situations, and when protected from direct sunlight, a lichen orchil dyed textile can preserve its brilliant colour. Urine vats weaken yarns (Paper V), but in the weft, no high breaking resistance was needed – thus the lichen orchil-dyed yarn was ideal for the weft yarn (Sample 9b) of the shawl cloak of Kaarina Kirkkomäki grave 1.

Unknown orange compound (Spectrum 11) detected in the warp of the Kaarina Kirkkomäki shawl cloak (Sample 9a) had a sharp, narrow peak in the UV-Vis spectrum ( $T_r$  15.96 min/ 385.5 nm), which resembles the peaks of the lichen compounds (Appendix 4). Since the peak did not match with any known dyestuff, it is worth considering a less used dyeing method for future experiments. For example dyeing with crottle (*Parmelia saxatilis*) is commonly done with the boiling water method and less often with the fermentation method with urine that dyes wool bright red (Goodwin 2003, 90–91). However, together with the TLC-detected tannin (Walton 2004a) Sample 9a was originally strongly reddish-orange.

Orcein-probably compounds are shown in Spectra 13, 14, 16 and 17. Also other compounds that are orchil-probably occur, showing similarities in the form of their peaks (Spectra 24 and 27). All in all, there are probable lichen-related compounds in Samples 8, 9b, 10, 11a, 11b and 12 (Appendix 4). The detected purplish lichen compounds, the blue indigotin and the unknown orange compounds (presumably red tannins) suggest, that the original colour of these samples was strongly purple, or dark maroon or deep bluish black – depending on the intensity of each dye.

Diamond green and an unknown red compound (Spectrum 22) were detected in Sample 15b (Appendix 4). These were interpreted as synthetic dyes and contamination from an unknown source (Paper I). No modern fibres were detected in SEM analysis, only degraded, prehistoric wool (van Bommel and Joosten 2013). However, judging by the form of the spectra, some of the lichen compounds detected in rock tripe (*Lasallia pustulata*)-dyed reference can be easily confused with synthetic dye fuchsine (van Bommel 2014). This suggests further research concerning the detected colourants of Sample 15b.

HPLC analysis detected lichen orcein-probably in the Hallstatt fragments 104, 126 and 137 (Grömer and Rösel-Mautendorfer 2013, 436, 456–457, 471; Hofmann-de Keijzer et al. 2013b, 150). The find 137 also contained indigoids, ellagic acid and an unknown orange (Grömer and Rösel-Mautendorfer 2013, 471). This is close to the dyestuff combination of Samples 8, 9b, 10, 11a, 11b and 12 (Appendix 4). Possibly the aim of the dyers was to produce intensive shades of colours, where indigoids and red compounds covered the fading of lichen purple.

Possible Scandinavian orchil (*Ochrolechia tartarea*) was detected by HPLC analyses in the Huldremose woman's scarf with a yellow-orange compound labelled as unknown 5, and luteolin and rhamnetin, suggesting the berries of the *Rhamnus* species (Vanden Berghe et al. 2009 and 2010). Possible yellow wall lichen dye (*Xanthoria parietina*) occurred in two samples from Borremose (Vanden Berghe et al. 2009). By TLC, lichen dye has been detected in the Vindolanda textiles from the 1<sup>st</sup> century AD (Taylor 1983) and in Thorsberg textiles from the 2<sup>nd</sup>–3<sup>rd</sup> centuries AD (Walton 1988a). Lichen purple was also in the textiles found in Anglo-Scandinavian York and in Hiberno-Norse Dublin (Walton 1988b) and in the 8<sup>th</sup>–11<sup>th</sup> century AD textiles found in Narsaq and in Herjolfsnæs in Greenland (Walton 2004b, 89). Lichen dyeing has been connected to the 9<sup>th</sup> century AD dyeing craft of the Frisian area (Walton 1988a). With regard to dating, Sample 9a from the beginning of the 11<sup>th</sup> century AD reflects especially this same Scandinavian and the Northern European dyeing tradition.

The Anglo-Scandinavian (Viking Age) and Hiberno-Norse lichen dyed textiles have been found in urban centres and consist of textiles used in everyday life (Walton 1988b). This is also case with Greenlandic textiles (Østergård 2004). The Kaarina Kirkkomäki cloak from grave 1 differs from the dark blue shawl cloaks by colour and by lack of bronze spiral decoration, so it possibly had a different symbolic meaning (Riikonen 2003). This suggests that the Kaarina Kirkkomäki grave 1 shawl cloak is a textile that was used in everyday life, like a blanket, or perhaps it is simply a textile that represents the wearer's personal taste.

After the decline of dye molluscs, different species of lichens such as *Roccella* in Italy, with plant and insect athraquinones and woad, were used to dye wool purple (Cardon 2007, 485, 510–512). People in the North were probably aware of the brilliant and not fading mollusc purple as a result of the Viking's activity in the Black Sea and Miklagård, where mollusc purple-dyed fabrics were produced until the middle of the 15<sup>th</sup> century AD (Cardon 2007, 576). Indeed, the silks of Mammen and Jelling contained orchil, obtained possibly from lichens of the genus *Lecanora* or *Roccella*, suggesting a Mediterranean origin (Walton 1991, 140; Vedeler 2014, 50). Finnish Late Iron Age silk finds (Tomanterä 1978; Lehtosalo-Hilander 1982b and 1982c; Tomanterä 2006a, 45) and the eastern silver coins (Talvio 2002) also indicate long-distance trade connections. Lichen purple can be seen as a reflection of the royal purple-dyed luxury garments of the Byzantine Empire – suggesting that the Northern lichen orchil was the poor men's purple with a brilliant hue.

## 6.7. Reference dyeings

Of 57 references only 5 dye sources matched archaeological samples. These were white bedstraw (*Galium album*, Ref. 2), Northern bedstraw (*Galium boreale*, Ref. 3) and Lady's bedstraw (*Galium verum*, Ref. 5) with the bedstraw-like ratio of alizarin and purpurin, woad (*Isatis tinctoria*, Refs. 23 and 24) with indigotin, indirubin, isatin and woad flavonoids, and rock tripe (*Lasallia pustulata*, Ref. 51) with orcein-probably compound and unknown lichen reds and blues.

In the modern world, where synthetic dyes are predominantly used in dyeing, *dyeing with natural dyes and alum mordant* seem as an old and traditional dyeing method. But probably this is just an illusion and the use of alum and boiling method may well be *too modern a technique* when preparing references for Late Iron Age dyes. Fermented dye baths and plant mordants might have given more matches.

Most of the references were dyed with an alum mordant and boiling method. Stainless steel kettles do not leak mordants and quickly conduct heat from an electric cooking plate to a dye bath. This dyeing, however, is not comparable with prehistoric dyeing: if any heating was used, it was possibly done using

an open fire or by adding heated stones to the dye bath. Fermentation baths can be prepared using wooden vessels. These might leak some colourants to yarns, but no evidence of this was detected by chromatographic analyses. In addition, cold dyeing method need no heating (Tetri 2008, 46–49) and possibly this method too was applied in the prehistoric dyeing.

In general, the yarns dyed with the fermentation method contained more unknown compounds than those dyed with the boiling method and an alum mordant. The reference dyed with a fermented bath made of silver birch bark (*Betula pendula*, Ref. 34) was dark salmon red in colour; only unknown flavonoids were detected, but no condensed tannins. In the reference dyed with roots of common tormentil (*Potentilla erecta*, Refs. 6 and 7) only a catechin was detected, although there also should be condensed tannins (Schweppe 1993, 514). Again, no tannins but only indigotin were detected in the reference dyed with fermented bark bath of silver birch (*Betula pendula*, Ref. 55) and tropical indigo powder (*Indigofera tinctoria*). This suggests that in an archaeological sample, the unknown reddish compounds might indicate the fermented tannins. However, more experiments are needed.

The amount of alizarin has been suggested to be dependent on the dyeing method used (Hofenk de Graaff 2004, 109–110), but no proof of this was found by the experiments. Reference 56 was dyed by boiling roots of Dyer's madder (*Rubia tinctorum*) in a fermented fir clubmoss bath (*Huperzia selago*), while reference 8 was dyed using fermented Dyer's madder without any mordant or boiling. Alizarin was the main colourant in both baths. Reference 57, dyed with fermented bark of alnus buckthorn (*Rhamnus frangula*) and fermented Dyer's madder, contained emodin and alizarin as main colourants – with no clue being given to the fermentation method.

An interesting phenomenon was found in the yarns dyed with crowberry (*Empetrum nigrum*) branches. The bright yellow reference was dyed in the summer (Ref. 13) using alum mordanted and the boiling method, while the orange reference (Ref. 14) was dyed in the winter and using the fermentation method. However, an orange shade of colour was also obtained using winter plants, alum and the boiling method (Paper V). This suggests that the orange colour might be a season- related phenomenon. With more experimental work it could be possible to reveal the periods which are optimal for fermenting and gaining the richest amount of condensed tannins on yarns.

No proper research has been made to systematically age the Finnish dyed reference material. The closest experiments have been carried out in Denmark, where a long experiment was performed by burying dyed fabric pieces in plastic boxes filled with soil and by preserving them in a green house (Ringgaard 2010). It was found that lichen and Dyer's madder dyes survive longer than yellow flavonoid dyes and, moreover, Dyer's madder has a tendency to preserve wool, though the reason for this is still not completely known (Ringgaard and Bruselius Scharf 2010). Moreover, in an anoxic and wet environment indigotin can return to its leuco-form and leak out of a textile (Ringgaard and Bruselius Scharf 2010).

In Lejre in Denmark, fading of dyes and shrinking of textiles occurred in a long burial experiment and after the 17-year test period wool items were completely decayed (Peacock 2004, 187). In an experiment made in Trondheim in Norway, linen fabric, antler, leather and dyed wool fabrics were buried for two years. As a result, colours of the weld-dyed (*Reseda luteola*) fabrics changed most, but some change was also apparent in the indigo-dyed and Dyer's madder-dyed samples (Peacock 2004, 192).

In the Finnish context, the preservation of organic material is demanding due to the acidic environment, and the changing seasonal temperatures with frost and non-frost conditions. Fermented, cold treated and aged references might have given a better match in the (U)HPLC analysis with the references and

the archaeological samples than the alum mordanted references. There are probably a limited number of plants, lichens, mushrooms, and other natural dye sources that can be used for dyeing. Accordingly, new references could provide matches with the many unknown colourants that are presented in this dissertation.

## 7. Conclusions

In this dissertation, I have shown that *three different dyeing methods* were known in Late Iron Age Finland. These methods were *vat dyeing*, *the fermentation method using tannins* and *mordant dyeing*.

Before this dissertation, the role of red tannins had remained a mystery; now it has been shown that these colourants probably are fermented tannins. I present that a reddish colour was dyed with fermented tannins using bark materials obtained from trees such as alder buckthorn (*Rhamnus frangula*) and silver birch (*Betula pendula*) and roots of common tormentil (*Potentilla erecta*). Since bedstraw dyes were available, but less commonly used, the use of red tannins has been an intentional selection. My interpretation is that the fermented tannins strengthen the yarns. This phenomenon was needed during the Late Iron Age when fabrics were woven in warp-weighted looms that required strong warp yarns.

Anthraquinones of bedstraws (*Galium* species) can be seen as an evidence of the mordant dyeing technique. Roots of Northern bedstraw (*Galium boreale*), white bedstraw (*Galium album*) and Lady's bedstraw (*Galium verum*) were likely sources for purpurin and alizarin in local textiles. Bedstraw anthraquinones were dyed either using the cold dyeing technique or in a bath warmed up with heated stones. Dyer's madder (*Rubia tinctorum*) in a prehistoric Finnish textile probably indicates an import. In general, red anthraquinone dyes can be connected to influences from the Central European dyeing tradition and the medieval world.

SEM-EDX element analysis and the UHPLC-detected maclurin suggest that clubmosses (*Lycopodium* species), eagle fern (*Pteridium aquilinum*) and horsetails (*Equisetum silvaticum* and *Equisetum arvense*) were probable sources of plant mordant. These plants accumulate aluminium (Al), silicon (Si) and potassium (K) and can thus be used as substitute for imported alum, which contains aluminium and potassium. Fermented mordant baths made of these plants fixed anthraquinones of bedstraws (*Galium* species) and flavonoids of woad (*Isatis tinctoria*) leaves to fibres. Possibly also eagle fern (*Pteridium aquilinum*), red sorrel (*Rumex acetosella*) and common chickweed (*Stellaria media*) were used in dyeing. These plant species contain potassium (K), and can be used as a substitute for cream of tartar.

The detected woad flavonoids indicate that the source of the blue colourant in Late Iron Age Finland was woad (*Isatis tinctoria*). My interpretation is that the blue was dyed using fresh or couched woad (*Isatis tinctoria*). This indicates that dyeing was done either with locally grown woad plants or more probably with imported woad balls. However, on account of the river routes to the Black Sea, the import of tropical indigo (*Indigofera tinctoria*) cannot be completely excluded. The indigotin-containing samples also contained several other colourful compounds, which means that pure sky blue was not shade colour of the textiles. With unknown yellow, orange and reddish compounds, woad flavonoids, tannins and lichen purple, the textiles acquired a very dark appearance or were almost black. Possibly sky blue garments did exist in Late Iron Age Finland, but not in the examined material.



Knowhow was needed to prepare vats not only for dyeing with woad but also for dyeing with lichens. In practice, lichen vats were much easier to handle since no constant control of temperature is needed. Because of the easy dyeing method and the local lichen resources, such as rock tripe (*Lasallia pustulata*), the utilisation of lichen dyes was probably common. I suggest that lichen purple can be connected to Scandinavian influences and be seen as part of the Northern European dyeing tradition. In a wider perspective, lichen purple can be connected to mollusc purple and distant influences from the South via the Viking's river routes.

Backish shade of colour was obtained by dyeing the yarns over and over again in the fermentation vats made of tannins, woad and lichens. This was performed in wooden vessels that were large enough and caused no iron or copper contamination on fibres which would have happen in metal cauldrons. Dyeing was time consuming, although it did not need constant active work at dyeing vessels. Textiles were dyed as fibres, yarns and as whole fabrics, which indicates good planning and deep understanding of the dyeing craft. Vats and over dyeing needed good skills and careful organising of all household activities, which probably added to the value and appreciation of the dyed textiles.

Concerning the yellow dyestuffs in the analysed samples of Finnish origin, I state that the yellow dyes such as quercetin, rutin, kaempferol, luteolin and apigenin as well as their equivalents have either completely faded, or these textiles never contained these flavonoids. My interpretation is that yellow flavonoid dyes of weld (*Reseda luteola*), saw-wort (*Serratula tinctoria*), Dyer's broom (*Genista tinctoria*) were introduced into the Finnish dyeing tradition during the Middle Ages. These dyes were connected to the import of alum, but also to the medieval fashion and the imported textiles containing the foreign yellow dyestuffs. The Finnish ethnographic recipes that describe the traditional yellow yielding dye plants are probably connected to the crafts of medieval and younger periods.

I state that the deep change in the culture at the beginning of the Middle Ages affected deeply the Finnish prehistoric dyeing tradition. The medieval world offered new beliefs and meanings for life, for textile making, and for dyes and shades of colours. As a result of these new cultural influences, red tannins were no longer used to strengthen yarns for warp-weighted looms nor were shawl cloaks dyed blackish blue in vats. The medieval culture provided a faster textile-making process with horizontal looms and spinning wheels as well as introduced the boiling method, alum and new imported dyestuffs for dyers.

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## Appendix 1: Summary of Papers I–V

### Paper I:

Vajanto, K. and van Bommel, M.R. 2014a. Dyed textiles from Late Iron Age Finland. *Fennoscandia Archaeologica* XXI, 61–78. The Archaeological Society of Finland, Helsinki.

This paper discusses Late Iron Age (ca. 800–1150/1300 AD) archaeological dyed woollen textile fragments found in Finland from inhumation burials, where textile fragments have been preserved in direct contact with bronze objects. The analysed 22 samples have been found in Luistari in Eura (4 samples), Kaarina Kirkkomäki in Turku (10 samples), Rikala in Halikko (4 samples), Tuukkala in Mikkeli (3 samples) and Yliskylä in Perniö (1 sample). The aim of this paper was to shed light on the used dyestuffs and local dyeing traditions. Based on earlier TLC analyses (Walton 2001a, 2001b and 2004) yarns from Kaarina Kirkkomäki graves 1 and 27 were dyed with red tannins. This differs from the dyes detected in contemporary European archaeological textiles, in which red was dyed mainly with Dyer's madder (*Rubia tinctorum*).

In the Finnish Late Iron Age material, most of the textiles are woven 2/2 twills. The warps are Sz-plied and wefts are z-spun. This was typical especially to the Finnish Late Iron Age textiles (Bender Jørgensen 1992). Based on this textile structure and the primitive wool from which the yarns were spun, we suggest that the analysed fragments are local products. One striped fragment found in Tuukkala in Mikkeli from the very end of the local Late Iron Age, has been woven using plain weave and half basket weave. We interpret that this is a foreign product.

Indigoids are present in most of the analysed fragments. Based on the date of the textiles, the most likely source of indigotin is woad (*Isatis tinctoria*). The fragments contain also alizarin and purpurin, which are anthraquinones. These are two main colorants of *Rubiaceae* plant family, but the ratio of the anthraquinones varies in different species. Accordingly, we interpret that the striped Tuukkala textile was dyed using imported Dyer's madder, or the textile itself was an imported product. Another textile, found in grave 56 in Luistari in Eura, was dyed using local bedstraws – presumably with roots of Northern bedstraw (*Galium boreale*). One sample found in grave 27 in Kaarina Kirkkomäki in Turku has a trace of purpurin, suggesting dyeing with local bedstraws.

Dye analysis detected luteolin and apigenin in the striped textile of Tuukkala, for first time in the Finnish prehistoric material. These dyestuffs are the main components of weld (*Reseda luteola*), dyer's broom (*Genista tinctoria*), sawwort (*Serratula tinctoria*), but are also present in dandelion (*Taraxacum officinale*) and yarrow (*Achillea millefolium*) (Hofmann-de-Keijzer et al. 2013: 153). Yellow flavonoids, which are common in the local Finnish dye plants (such as rutin and quercetin) are absent in all the analysed Finnish fragments. It is suggested in our paper that that yellow-yielding plants were not used at all in Late Iron Age Finland or the dyestuffs have degraded completely.

Several unidentified red and orange components possibly indicate the use of an unknown and local dye resource. Some of these compounds are presumably anthraquinones. An unknown red component has an absorption maximum of 468 nm. The same component has been found in three Early Modern samples from Oulu Cathedral (Lipkin et. al. 2015). Some of the unknown colorants are in the same textiles in which TLC analysis found the red tannins. However, without a matching dye reference, the unknown colorants remain unidentified.

## Paper II:

**Vajanto, K. 2014. Nålbinding in Prehistoric Burials – Reinterpreting Finnish 11<sup>th</sup>–14<sup>th</sup>-century AD Textile Fragments.** In A.-K. Salmi, T. Äikäs and J. Ikäheimo (eds.), *Sounds Like Theory: XII Nordic Theoretical Archaeology Group Meeting in Oulu 25.-28.4.2012. Monographs of the Archaeological Society of Finland 2*, 21– 33. [http://www.sarks.fi/masf/masf\\_2/SLT\\_02\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_2/SLT_02_Vajanto.pdf)

In this paper I discuss Finnish prehistoric woollen textiles made with the nålbinding technique. These textiles are from Late Iron Age inhumation burials and dated to the 11<sup>th</sup>–14<sup>th</sup> centuries AD. I discuss these in connection with the data obtained from ethnographic evidence. In a survey made in 1957, was obtained folklore concerning nålbinding and in addition, nålbound textile samples. The analysis of this survey was presented by Kaukonen in 1960. My aim is to criticize the use of the ethnographic evidence a main explanation source of the archaeological textile finds.

For my paper, I made a case study of the three coloured nålbound fragments found in grave 56 in Eura in Luistari. According to HPLC analysis, the red yarn of the fragment has been dyed with Northern bedstraw (*Galium boreale*). The yellowish yarn is probably undyed or leaked dyes from other yarns have contaminated it. The blue yarn was not analysed, but indigotin was detected in the other samples. Probable source of indigotin was woad (*Isatis tinctoria*).

Based on my experiments with the nålbinding technique, I suggest that the double spiral technique produces a textile structure that is identical to the nålbound, three-coloured fragment of Eura Luistari NM 18000:1702. Mitten with a thumb was my first interpretation of the Eura Luistari fragment (Vajanto 2003). But the double spiral technique allows no longer the interpretation with a thumb. Indeed, the prehistoric Finnish nålbound finds could have been some kind of pouches of unknown purpose. In addition, I present, that the absence of the double spiral technique from the younger material indicates changes in the nålbinding tradition.

In general, there is no evidence for thumbs or heels in other prehistoric fragments either, which makes the “mittens and socks” interpretation questionable. Many (ca. 50%) of the Finnish prehistoric nålbound textile material is colourful, and the finds differ from the white funeral mittens that are described in the survey material obtained in the 20<sup>th</sup> century AD. I state, that the ethnographic nålbound textiles and Finnish folklore data concerning the nålbinding technique have strongly influenced the interpretations of Finnish archaeological finds. Accordingly, the ethnographic data concerning to nålbinding should not be used as an ethnographic parallel to the prehistoric material. I suggest that the archaeological fragments should be interpreted on the basis of their individual data, without ethnographically oriented expectations.

In addition, I suggest that in the Finnish prehistoric finds, placement near the hand bones does not confirm the nålbinding finds as the remains of mittens. In burials this area often has most of the bronze remains, which preserve the organic material and textiles. I therefore present, that the placement indicates only the optimal place of preservation for organic material. My conclusion is that ethnographic analogy should be applied in archaeological textile research with great caution.

## Paper III:

**Vajanto, K. 2014. Finnish shipwreck textiles from the 13<sup>th</sup>–18<sup>th</sup> centuries AD. In S. Lipkin and K. Vajanto (eds.), *Focus on Archaeological Textiles: Multidisciplinary Approaches. Monographs of the Archaeological Society of Finland* 3, 116–131. [http://www.sarks.fi/masf/masf\\_3/MASF3\\_09\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_3/MASF3_09_Vajanto.pdf)**

In this paper I discuss textile fragments that have been found in shipwrecks in the Finnish waters. The finds have been dated to the 13<sup>th</sup>–18<sup>th</sup> centuries. Visual analysis is applied on all samples, HPLC analysis and XRF are performed to samples from *Lapuri*, *Egelskär* and *Mulan* to detect dyes, mordants and contamination, FTIR and SEM are applied on *Vrouw Maria* samples in order to identify certain fibres. Dye analyses of *Sankt Mikael* and *Vrouw Maria* are not discussed in this paper.

The fragments from Lapuri shipwreck (13<sup>th</sup> century AD) have been woven in three-shaft twill (1/2 or 2/1), using very tight yarns. In practice, the tight twist and the tight ply increase the breaking resistance and the tenacity of the fabric. The fibres were in good condition, organic, but showing a layer of iron (Fe) particles on the fibres surfaces. Ellagic acid was detected by HPLC, but this finding is interpreted as contamination from the archaeological context. From ethnographic sources it is known that woollen sails were *smörred* i.e. treated with red ochre. I thus suggest that the Lapuri fragments are remains of a *smörred* woollen sail.

The find of *Egelskär* (14<sup>th</sup> century) has no visible textile structures but consists of a thick layer of sheep wool fibres. I interpret this find as remains of a sheepskin. The fibres were quite degraded and contained iron as their main element, accompanied with small quantities of tin (Sn). I present that these elements originated from the archaeological context and has accumulated on the fibres from the iron bars of the cargo. I suggest this finding is the result of contamination from the submarine environment or the shipwreck itself, and does not indicate intentional dyeing.

The woollen tabby from *Mulan* shipwreck (early 17<sup>th</sup> century) has been woven using s- and z-spun yarns, but no dyes were found in the HPLC analysis. Accordingly, I suggest that the white woollen tabby from the *Mulan* wreck is possibly a fragment of a flag.

The sock from the *Sankt Michel* (wrecked in 1747) has been spun from fine, pink-dyed Merino wool – it is thus a very expensive product on the basis of its costly raw materials. The quilted petticoat from the *Sankt Michel* has a dark and coarse batting made of Hairy type of wool. This batting has possibly been dyed with indigo, because the wool fibres have a bluish hue and the scales are opened as if they have suffered from an alkaline vat. I present, that this crude wool has been selected to decrease the cost of the quilted petticoat due to its invisible placement within two silk layers.

The red fragments from the *Vrouw Maria* (wrecked in 1771) consist of several different fibres. Sheep wool, mohair, silk, possible nettle and cotton are presented as findings in the TLM and the SEM images. Probable mohair fibres are present in the z-spun warp yarns. The loosely s-spun weft contains cotton and fine sheep wool fibres. The few possible nettle and silk fibres are possibly not connected to the red fabric, but might be the result of contamination from other fabrics in the cargo. I suggest that the red fibres have been dyed before the spinning, possibly using two different dyeing methods for the different fibre types. According to my research, I suggest that the brilliant red textile in the *Vrouw Maria* was expensive, high quality camlet.

In general, shipwreck textiles from different time periods enrich our knowledge of the transportation of fabrics and cultural influences via the maritime fairways of the Baltic Sea.

## Paper IV:

**Vajanto, K. 2013. Fibre Analysis of Late Iron Age, Early Modern and Modern Finnish Wools. *Fennoscandia Archaeologica* XXX, 81– 94. The Archaeological Society of Finland, Helsinki.**

This paper compares archaeological wools found in Finland to the modern wools of Finnsheep and Finnish Jaalasheep. The archaeological finds originate from three inhumation burials: Luistari in Eura (4 samples), Tuukkala in Mikkeli (2 samples), Halikko in Rikala (3 samples) and shipwrecks found in Lapuri (3 samples) and Egelskär (1 sample). My aim is to shed light on the provenance question of textiles and on wool processing through fibre analysis. In addition, because no data of Finnish Late Iron Age raw wool staples was available, one aim of this paper was to find modern reference wool that is identical or very close to the prehistoric wool.

According to my analyses the archaeological samples contain *Hairy*, *Hairy medium*, *Generalized medium*, and *Medium* wools and an intermediate type. These have been identified in the previous analyses from the Finnish materials (Kirjavainen Ryder 1978; Kirjavainen and Riikonen 2005 and 2007). My interpretation is that all the researched archaeological samples could derive from local Finnish sheep breeds, since probably the flocks in the past did not produce uniform wool and that the wools were possibly sorted and mixed. In addition, I suggest that an imported product could be revealed not only by the wool type alone, but by taking into consideration the archaeological context, possible atypical textile structures, and exceptional wool types.

The researched Jaalasheep have underwool and outer coat hair in fleece, which fibre diameter distribution is comparable to the archaeological samples. In Jaalawool, the amount of the medullated fibres varies between individual sheep and a high proportion of medullated fibres can also be found in lamb's wool. In addition, the underwool and outer coat hair can be in different colours. Indeed, I state that the wool of modern Jaalasheep is comparable to the Finnish archaeological wools on account of the double coated structure of fleece and the heterogeneity within a flock. Thus, it can be used as reference material in wool studies and in experimental archaeology when the aim is to explain phenomena observed in the archaeological samples.

I suggest that moulting spring wool of modern Jaalasheep is similar to the wools found in archaeological yarns. Accordingly, archaeological yarns were possibly spun directly from shed underwool staples without hand sorting. My conclusion is that the presence of hair in the archaeological yarns in general can indicate intentional preserving or adding of long hair during the spinning. This diminishes the amount of waste wool, but also increases the yarn's breaking resistance.

Rare orange fibres are found in fleeces of some individuals of among Jaalasheep, most often in lamb's wool. Accordingly, I suggest that the orange fibres in archaeological textiles might contain the rare pigment phaeomelanin, especially when no dyes can be detected by HPLC analysis. I suggest that this might be the case in sample KM 38090:682 from Tuukkala in Mikkeli, which is visually strongly orange in colour.



## Paper V:

Vajanto, K. 2014. Textile standards in experimental archaeology. In S. Lipkin and K. Vajanto (eds.), *Focus on Archaeological Textiles: Multidisciplinary Approaches. Monographs of the Archaeological Society of Finland* 3, 62–75. [http://www.sarks.fi/masf/masf\\_3/MASF3\\_05\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_3/MASF3_05_Vajanto.pdf)

In this paper I discuss the ISO textile standards that are the testing methods of the textile industry. My focus is on the archaeological finds and on experimental archaeology. I show the results of my experiments that I have made using ISO textile standards. I have tested the breaking resistance of yarns (standards ISO 2062:2009 and ISO 1144:1973) and the colour fastness of natural dyes for perspiration (standards ISO 105-E04:2008, ISO 105-F01–F07:2009 and ISO 105-A03:1993).

My test material in the breaking resistance test consists of Finnish machine- and hand-spun wool yarns, which I have dyed with three different dyeing methods and three natural dyes. These are mordant dyeing and boiling with roots of Dyer's madder (*Rubia tinctorium*), the fermentation method with alder buckthorn (*Rhamnus frangula*) bark, and alkaline vat dyeing with rock tripe (*Lasallia pustulata*). The reference yarns are undyed. My study offers new insights for understanding the selections made for the yarns and dye materials in the past.

My experiments concerning the yarns breaking resistance show that the tested hand-spun yarns are stronger than machine-spun yarns. In addition, the tenacity of the yarns correlates with the dyeing methods. Dyeing with rock tripe in fermented urine bath, which is alkaline, is harmful to some yarns, but in general this dyeing method is not the worst one. The yarns that have an alum mordant and have been dyed using the boiling method with Dyer's madder are quite regularly the weakest ones. Especially double-coated wool suffers from the boiling method. Strength is retained or extra strength gained if the yarn has been dyed in a fermented alder buckthorn bath. I state that the selection of the dyeing method might have been important in the past, when the yarns spun from the double-coated wool were woven on warp-weighted looms.

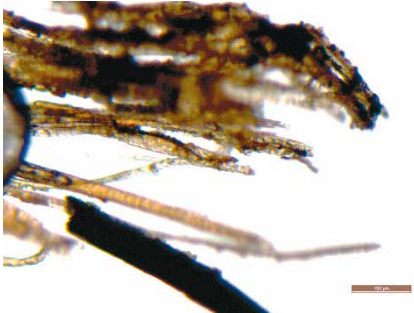



Colour fastness of natural dyes for perspiration is tested with yarns that I dyed using three different dyeing methods. These are the boiling method with an alum mordant; the fermentation of tannins and the fermented urine vat. In addition, one dyeing is performed using a fermented clubmoss mordant (*Lycopodium* species) and the boiling method for the dye. The dyes are obtained from roots of common tormentil (*Potentilla erecta*), silver birch (*Betula pendula*) leaves and bark, rock tripe (*Lasallia pustulata*), crottle (*Parmelia saxatilis*), alder buckthorn (*Rhamnus frangula*) bark, heather (*Calluna vulgaris*), crowberry (*Empetrum nigrum*), wild rosemary (*Rhododendron tomentosum*), bog rosemary (*Andromeda polifolia*), roots of Dyer's madder (*Rubia tinctorium*) and Northern bedstraw (*Galium boreale*) as well as from the purple flowers of common lupine (*Lupinus polyphyllus*).


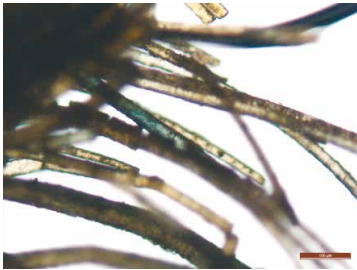

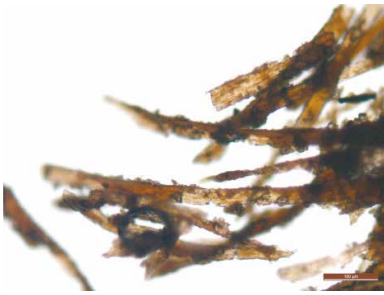
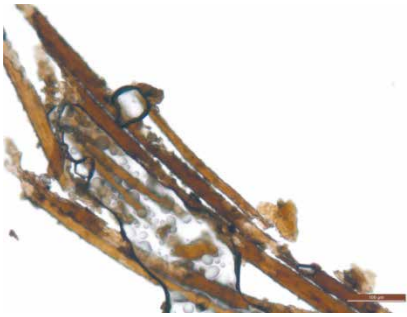
According to my experiments, natural colorants withstand perspiration very well. The test cause only very small fading of colours or only a little staining. In addition, the colour fastness for perspiration is excellent in yarns dyed with lupine and rock tripe that are often not valued by modern dyers due to low light fastness. The expectations and demands for the permanence of dyes in colourful textiles have probably changed during the last century. I suggest that the standardised textile testing methods that are commonly used in the textile industry can produce good, repetitive data also for experimental textile archaeology. In addition, I suggest that term *experimental textile archaeology* could be changed to *empirical textile archaeology* based on the empirical research methods of the textile industry.


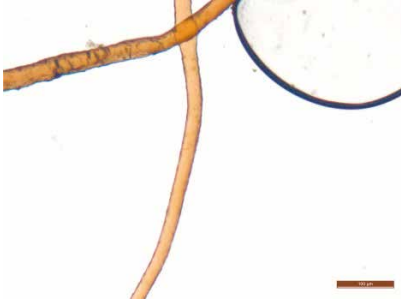
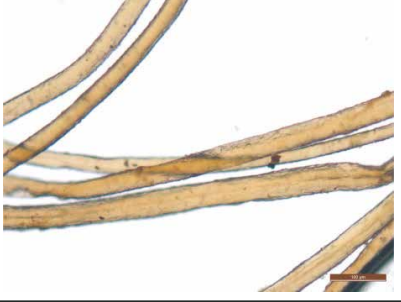

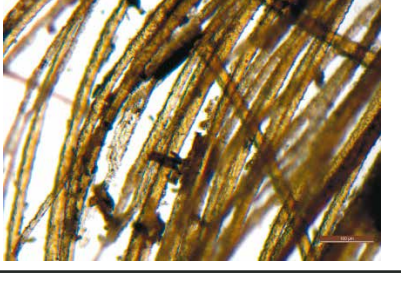
## Appendix 2: Archaeological samples

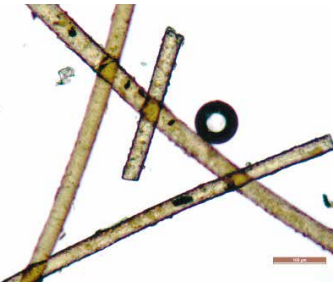




Archaeological samples originating from the same fragment are labelled as a-d.






The KM number (and NM number in Paper II) refers to the archaeological collections of the National Museum of Finland. SMM numbers refers to the collections of the Maritime Museum of Finland.

Sample	Find	Image	Notes	Date (AD), Paper discussed in
<b>1a.</b> <b>1b.</b>	Eura Luistari KM 18 000:1702, red stripe, nålbinding		Yarns dyed before nålbinding. Attached nettle and animal fibres.	Early 11th centuries P I, P IV
<b>1c.</b>	Eura Luistari KM 18 000:1696, yellow stripe, nålbinding		Yarns dyed before nålbinding. Attached nettle and animal fibres.	Viking I-period 9–10th centuries P II
<b>2a</b>	Eura Luistari KM 18000:2071, warp, 2/2 twill		Dyed as whole fabric.	Viking I-period 9th–10th centuries P I, P IV
<b>2b.</b>	Eura Luistari KM 18000:2071, weft, 2/2 twill		Dyed as whole fabric; the yarn has areas without blue colour caused by warps. Same effect was with the samples 2b, 3a and 3b.	Viking I-period 9th–10th centuries P I, P IV







<b>3a.</b>	Eura Luistari KM 18000:2084, warp, 2/2 twill		Dyed as whole fabric, see above.	Viking I-period 9th–10th centuries P I, P IV
<b>3b.</b>	Eura Luistari KM 18000:2084, weft, 2/2 twill		Dyed as whole fabric; the yarn has areas without blue colour caused by warps. Same effect was with the samples 2b, 3a and 3b.	Viking I-period 9th–10th centuries P I, P IV
<b>4a.</b>	Halikko Rikala KM 12690:168a, warp, 2/2 twill		Yarns dyed before weaving.	11–12 th centuries P I, P IV
<b>4b.</b>	Halikko Rikala KM 12690:168b, warp, 2/2 twill		Yarns dyed before weaving.	11– 12th centuries P I, P IV
<b>4c.</b>	Halikko Rikala KM 12690:168c, weft, 2/2 twill		Yarns dyed before weaving.	11–12th centuries P I, P IV

4d.	Halikko Rikala KM 12690:168d, weft, 2/2 twill		Yarns dyed before weaving.	11–12th centuries P I, P IV
5a.	Mikkeli Tuukkala KM 9770:5, red stripe, half-basket twill		Dyed before weaving, possibly as yarns or fibres.	13–14th centuries P I
5b.	Mikkeli Tuukkala KM 9770:5, light coloured stripe, half-basket twill		Undyed?	13–14th centuries P I
5c.	Mikkeli Tuukkala KM 9770:5, tabby		Dyed before weaving, possibly as yarns or fibres.	13–14th centuries P I
6.	Mikkeli Tuukkala KM 38090:682, 2/2 twill		Undyed? Orange (tan) wool?	14th century P IV

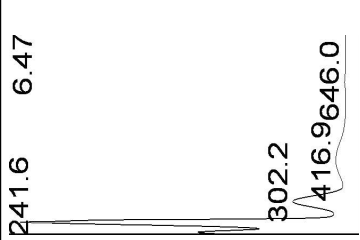
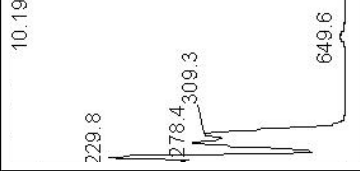
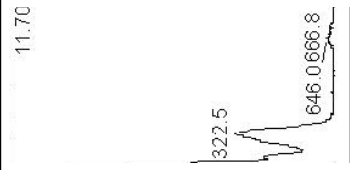

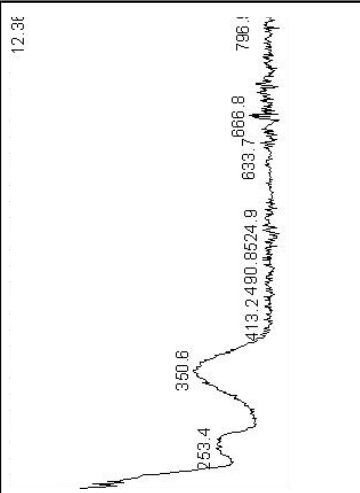
7.	Mikkeli Tuukkala KM 38090:682, yarn near oval shoulder brooch		Undyed?	13–14th centuries P IV
8.	Perniö Yliskylä KM 2912:53, warp, 2/2 twill		Dyed before ply- ing, or even be- fore spinning. Very rich in blue dye.	11th century P I
9a.	Turku Kaarina Kirkkomäki KM 12687:H1:20, warp, 2/2twill		Dyed as yarn or even before spin- ning.	11th century P I
9b.	Turku Kaarina Kirkkomäki KM 12687:H1:20, weft		Dyed as yarn or even before spin- ning.	11th century P I
10.	Turku Kaarina Kirkkomäki KM 27025:H27:168, warp, 2/2 twill		Dyed as yarn or even before spin- ning.	11th century P I

<b>11a.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:203, warp, 2/2 twill		Dyed as yarn or even before spin- ning.	11th century P I
<b>11b.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:203, weft, 2/2 twill		Dyed as yarn or even before spin- ning.	11th century P I
<b>12.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:230b, warp, finger woven braid		Dyed as yarn.	11th century P I
<b>13.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:235, warp, braided band		Dyed as yarn or even before spin- ning.	11th century P I
<b>14.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:237, warp, tablet woven band		Dyed as yarn before plying.	11th century P I

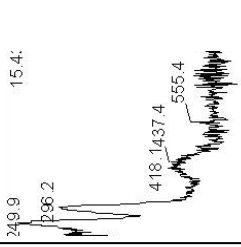
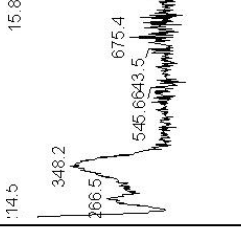
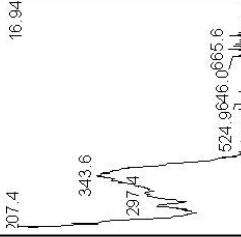
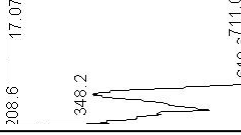
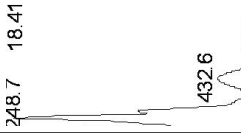


<b>15a.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:239, warp, light coloured, finger woven braid		Dyed as yarn.	11th century P I
<b>15b.</b>	Turku Kaarina Kirkkomäki KM 27025:H27:239, warp, dark coloured, finger woven braid		Dyed as yarn.	11th century P I
<b>Shipwreck textiles:</b>				
<b>16a.</b>	Lapuri SMM 2592:8, weft? three-shaf twill		Undyed. Smörred?	13th century P III, P IV
<b>16b.</b>	Lapuri SMM 1393:27, warp? three-shaf twill		Undyed. Smörred?	13th century P III, P IV
<b>16c.</b>	Lapuri SMM 2592:8, darning thread		Undyed. Naturally pigmented brown wool.	13th century P III, P IV
<b>17.</b>	Egelskär SMM 1657, 342006:16, fur?		Undyed.	14th century P III, P IV

Appendix 3: HPLC spectra of the archaeological Samples 1a–5c

Find	Isatin	Unknown. 1. Maclurin-equivalent?	Unknown. 2. Flavonoid?	Unknown. 3. Flavonoid?	Woad flavonoid
					
1a. (+)					
1b. (+)					
1c.					X
2a.	X	X	X	X	
2b.	X	X	X	X	
3a.	X	X	X	X	
3b.	X	X	X	X	
4a.		X			X
4b.		X	X	X	
4c.		X	X	X	
4d.		X	X	X	
5a.		X			
5b.		X			
5c.		X			

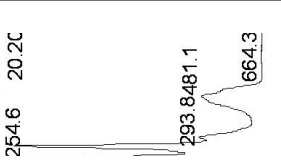
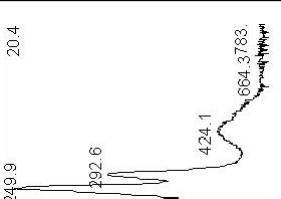
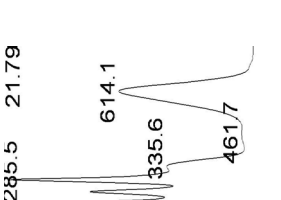
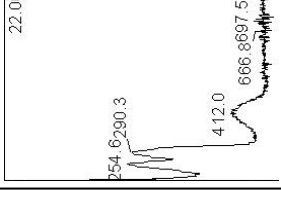
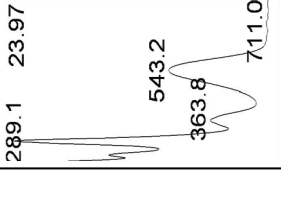
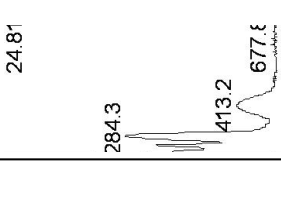
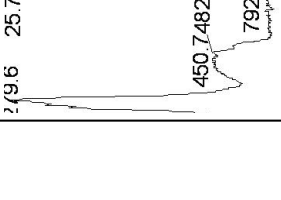


Find	Unknown 4. Anthraquinone?	Luteolin	Apigenin	Chrysoeriol?	Alizarin
					
1a. (+)					X
1b. (+)					X
1c.					X
2a.				X	
2b.				X	
3a.				X	
3b.				X	
4a.					
4b.					
4c.					
4d.					
5a.	X				X
5b.					
5c.	X	X (trace)	X (trace)		X (trace)


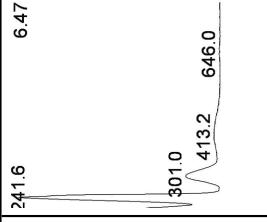
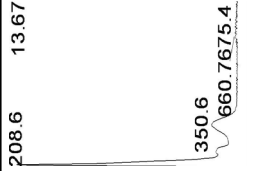
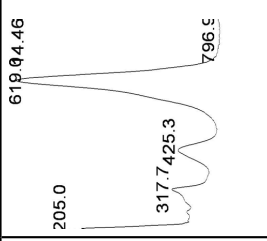
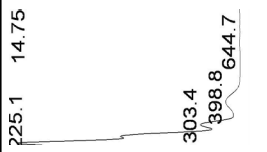
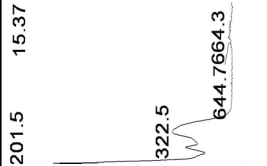
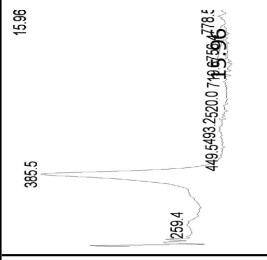
Samples marked with (+) were analysed at Royal Institute for Cultural Heritage (KIK-IRPA) in Belgium by Ina Vanden Berghe.

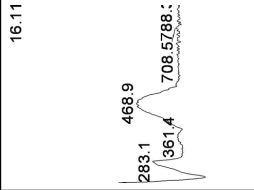
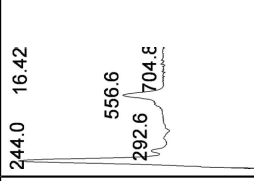
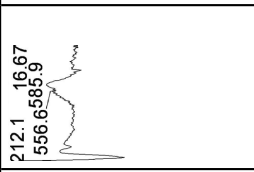
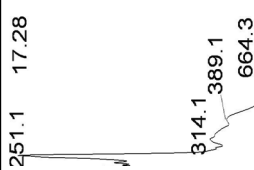

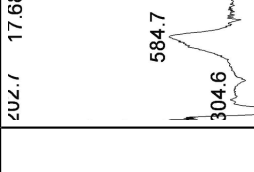
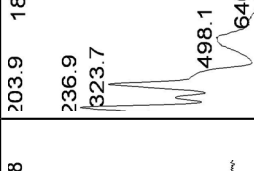

All other samples were analysed at the Cultural Heritage Agency of the Netherlands (RCE) by Maarten R. van Bommel and Art Ness

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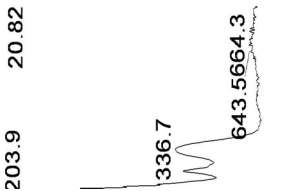
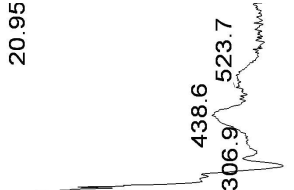

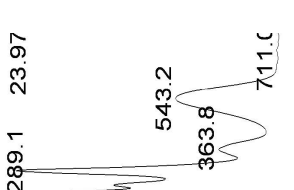

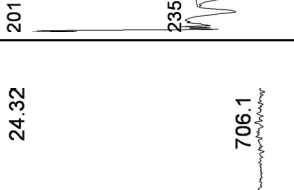
Find	Purpurin	Unknown 5. Anthraquinone?	Indigotin	Rubiadin	Indirubin	Unknown 6. Anthraquinone?	Unknown 7. Anthraquinone?
							
1a. (+)	X						
1b. (+)	X						
1c.	X		X	X	X	X	X
2a.			X		X		
2b.			X		X		
3a.			X		X		
3b.			X		X		
4a.			X (trace)				
4b.			X (trace)				
4c.			X (trace)				
4d.			X (trace)				
5a.	X	X	X	X			
5b.							
5c.	X (trace)			X			

## Appendix 4: UHPLC and HPLC spectra of the archaeological Samples 8–16b

Find	Isatin-equivalent	Isatin	Unknown 8. Flavonoid?	Diamond green? Lichen dye?	Unknown 9. Flavonoid?	Unknown 10. Flavonoid?	Unknown 11. Lichen?
							
8.	X	X			X		
9a.		X (trace)					X
9b.		X (trace)					
10.		X					
11a.		X (trace)					
11b.		X					
12.		X (isatin-probably)					
13.							
14.			X			X	
15a.		X					
15b.				X			
16b. (+)							

Find	Unknown 12. Anthraquinone?	Unknown 13. Lichen?	Unknown 14. Lichen?	Unknown 15. Flavonoid?	Unknown 16. Lichen?	Unknown 17. Lichen?	Unknown 18.	Unknown 19. Woad red?
								
8.	X			X			X	
9a.								
9b.	X	X	X		X	X		
10.		X		X				
11a.								X
11b.		X						X
12.		X						
13.								
14.								
15a.								
15b.								
16b. (+)								

Find	Unknown 20. Flavonoid?	Unknown 21.	Unknown 22. Lichen?	Unknown 23.	Unknown 24. Lichen?	Unknown 25.	Indigotin
8.		X				X	X
9a.							
9b.							X
10.				X			X
11a.				X	X		X
11b.				X	X		X (trace)
12.	X			X			
13.				X			
14.				X			
15a.							X
15b.			X				X
16b. (+)							

Find	Unknown 26. Flavonoid?	Unknown 27. Lichen?	Unknown 28.	Indirubin	Unknown 29. Anthraquinone?	Unknown 30. Anthraquinone?
						
8.	X			X		
9a.						
9b.				X	X	X
10.				X		
11a.		X		X (trace)		
11b.		X		X (trace)		
12.						
13.						
14.	X		X			
15a.				X (trace)		
15b.		X				
16b. (+)						

Find	Purpurin?	Unknown 31. Flavonoid?	Unknown 32.	Unknown 33. Anthraquinone?	Unknown 34.	Unknown 35.	Unknown 36.	Unknown 37.
8.			X	X				X
9a.								
9b.	X							
10.								
11a.			X	X				
11b.				X				
12.								
13.						X	X	X
14.								
15a.								
15b.								
16b. (+)		X						

Samples marked with (+) were analysed at the Royal Institute for Cultural Heritage (KIK/ IRPA) in, Belgium by Ina Vanden Berghe.

All other samples were analysed at the Cultural Heritage Agency of the Netherlands (RCE) by Maarten R. van Bommel and Art Ness Proaño Gaibor

## Appendix 5: HPLC results of the reference dyeings

No.	Colour	Recipe	Dye source	Dyeing method	Dye material	Main colorants
<b>Roots</b>						
1.		Folk, experim.	<i>Comarum palustre</i> Purple marshlocks	Alum + cream of tartar, boiled	Dried roots	Ellagic acid, unknown red
2.		Hassi	<i>Galium album</i> White bedstraw	Alum + cream of tartar, boiled	Fresh roots	Purpurin, rubiadin, alizarin, nordamnacanthal, unknown anthraquinones
3.		Hassi	<i>Galium boreale</i> Northern bedstraw	Alum + cream of tartar, boiled	Fresh roots	Purpurin, alizarin, rubiadin, unknown anthraquinones
4.		Hassi	<i>Galium palustre</i> var. <i>balticum</i> Common marsh bedstraw	Alum + cream of tartar, boiled	Fresh roots	Purpurin, rubiadin, unknown anthraquinones
5. (+)		Hassi	<i>Galium verum</i> Lady's bedstraw	Alum + cream of tartar, boiled	Fresh roots	Purpurin, rubiadin, nordamnacanthal alizarin, xanthopurpurin
6. (+)		Folk, experim.	<i>Potentilla erecta</i> Common tormentil	Alum + cream of tartar, boiled	Fresh roots	Ellagic acid
7.		Folk, experim.	<i>Potentilla erecta</i> Common tormentil	Fermented	Fresh roots	Ellagic acid and its equivalents
8. (+)		Experim.	<i>Rubia tinctorum</i> Dyer's madder	Fermented	Dried roots	Alizarin, nordamnacanthal, purpurin, rubiadin, xanthopurpurin
<b>Evergreen shrubs</b>						
9.		Folk, experim.	<i>Andromeda polifolia</i> Bog rosemary	Alum + cream of tartar, boiled	Fresh plants	Hyperoside, quercitrin, myricitrin, unknown flavonoid
10.		Hassi	<i>Arctostaphylos uva-ursi</i> Bearberry	Alum + cream of tartar, boiled	Fresh plants	Kaempferol, quercetin, unknown flavonoid
11.		Hassi	<i>Calluna vulgaris</i> , Heather winter plant	Alum + cream of tartar, boiled	Fresh plants	Quercetin, rutin, kaempferol, luteolin-equivalent, unknown. flavonoids, unknown red compounds
12.		Hassi	<i>Calluna vulgaris</i> , Heather summer plant	Alum + cream of tartar, boiled	Fresh plants	Hyperoside, quercetin, kaempferol
13.		Hassi	<i>Empetrum nigrum</i> , summer plant Crowberry	Alum + cream of tartar, boiled	Fresh plants	Quercetin, rutin, unknown flavonoid, unknown orange and red compounds



14.		Experim.	<i>Empetrum nigrum</i> , Crowberry winter plant	Fermented	Fresh plants	Quercetin, rutin, unknown flavonoids, unknown compounds, unknown red compounds
15.		Hassi	<i>Rhododendron tomentosum</i> Wild rosemary	Alum + cream of tartar, boiled	Fresh plants	Quercetin, rutin, kaempferol, unknown red compounds
<b>Weeds and leafs</b>						
16.		Hassi	<i>Alchemilla vulgaris</i> Lady's mantle	Alum + cream of tartar, boiled	Fresh leaves	Ellagic acid, quercetin, rutin, luteolin, apigenin
17.		Hassi, folk	<i>Betula pendula</i> , Silver birch tiny spring leaves	Alum + cream of tartar, boiled	Fresh leaves	Rutin, quercetin, ellagic acid, kaemp- ferol, unknown flavonoids, unknown red compounds
18.		Hassi	<i>Betula pendula</i> Silver birch	Alum + cream of tartar, boiled	Fresh leaves	Quercetin, apigenin- equivalent, unknown flavonoids
19.		Hassi	<i>Betula pubescens</i> White birch	Alum + cream of tartar, boiled	Fresh leaves	Apigenin, quercetin, kaempferol, ellagic acid-equivalent, unknown flavonoids
20.		Hassi	<i>Epilobium angustifolium</i> Rosebay willowherb	Alum + cream of tartar, boiled	Fresh leaves	Ellagic acid, quercetin, kaempferol
21.		Hassi	<i>Filipendula ulmaria</i> Meadowsweet	Alum + cream of tartar, boiled	Fresh leaves	Ellagic acid, quercetin, rutin
22.		Hassi , experim.	<i>Humulus lupulus</i> Hop	Alum + cream of tartar, boiled	Fresh leaves	Kaempferol, rutin, quercetin
23.		Experim.	<i>Isatis tinctoria</i> Woad	Alum + cream of tartar, boiled	Fresh leaves	Ellagic acid, apigenin- equivalent, luteolin- equivalent, unknown woad flavonoid, unknown compounds, indigotin, indirubin
24.		Experim.	<i>Isatis tinctoria</i> Woad	Fermented in urine vat	Fresh leaves	Indigotin, indirubin, isatin unknown flavonoids
25.		Hassi	<i>Rhamnus frangula</i> Alder buckthorn	Alum + cream of tartar, boiled	Fresh leaves	Kaempferol, quercetin, emodin, chrysophanic acid-equivalent, rhamnetin-equivalent
26.		Hellen	<i>Rumex acetosella</i> Red sorrel	Alum + cream of tartar, boiled	Fresh plants	Luteolin, apigenin, maclurin-equivalent

27.		Hellen	<i>Stellaria media</i> Common chickweed	Alum + cream of tartar, boiled	Fresh plants	Apigenin glycosides
<b>Flowers</b>						
28.		Hassi	<i>Anthemis tinctoria</i> Dyer's chamomile	Alum + cream of tartar, boiled	Fresh flowers	Apigenin, luteolin
29.		Experim.	<i>Lupinus polyphyllus</i> Lupine	Alum + cream of tartar, boiled	Fresh flowers	Apigenin, luteolin-7-glycoside, genistin, anthocyanins
30.		Experim.	<i>Scilla siberica</i> Siberian squill	Alum + cream of tartar, boiled	Fresh flowers	Apigenin glycoside, luteolin glycoside
31.		Experim.	<i>Viola tricolor</i> Heartsease	Alum + cream of tartar, boiled	Fresh flowers	Rutin, quercetin, unknown flavonoids, anthocyanins
<b>Barks</b>						
32.		Hassi, folk	<i>Alnus glutinosa</i> Alder	Alum + cream of tartar, boiled	Dried barks	Quercetin, unknown flavonoids
33.		Hassi, folk	<i>Betula pendula</i> Silver birch	Alum + cream of tartar, boiled	Dried barks	Quercetin, kaempferol, catechin-equivalent, unknown red compounds
34.		Folk, experim.	<i>Betula pendula</i> Silver birch	Fermented	Fresh barks	Unknown flavonoid
35.		Hassi	<i>Malus domestica</i> Apple tree	Alum + cream of tartar, boiled	Dried barks	Quercetin, kaempferol, unknown red compounds
36.		Experim.	<i>Populus tremula</i> Aspen	Alum + cream of tartar, boiled	Dried barks	Several unknown compounds, unknown red compounds
37.		Experim.	<i>Rhamnus frangula</i> Alder buckthorn	Fermented	Dried barks	Emodin, chrysophanic acid, unknown yellow compounds
38.		Hassi	<i>Salix</i> species Willow	Alum + cream of tartar, boiled	Dried barks	Myricetin, quercetin, kaempferol, unknown red compounds
39.		Hassi	<i>Sorbus aucuparia</i> Rowan	Alum + cream of tartar, boiled	Dried barks	Ellagic acid, quercetin, unknown red compounds
<b>Sprigs</b>						
40.		Hassi	<i>Juniper communis</i> Juniper	Alum + cream of tartar, boiled	Fresh sprigs	Kaempferol, apigenin, unknown red and orange compound, unknown flavonoid
41.		Hassi	<i>Picea abies</i> Norway spruce	Alum + cream of tartar, boiled	Dried sprigs	Apigenin, rutin, ellagic acid

Cones						
42.		Hassi	<i>Alnus glutinosa</i> Alder	Alum + cream of tartar, boiled	Dried cones	Ellagic acid, quercetin, luteolin, unknown red compounds
43.		Hassi	<i>Picea abies</i> Norway spruce	Alum + cream of tartar, boiled	Dried cones	Kaempferol, ellagic acid, unknown flavonoids, unknown reds
Pteridophytes						
44.		Experim.	<i>Equisetum arvense</i> , Field horsetail summer stem	No mordant, boiled	Fresh plants	Possible glycosides of luteolin, apigenin and rutin, unknown orange compounds
45.		Experim.	<i>Equisetum silvaticum</i> , Wood horsetail summer stem	No mordant, boiled	Fresh plants	Rutin, kaempferol-equivalent
46.		Experim.	<i>Huperzia selago</i> Fir clubmoss	Fermented	Fresh plants	Maclurin and maclurin-equivalents, luteolin
47. (+)		Experim.	<i>Lycopodium annotinum</i> Stiff clubmoss	Fermented	Fresh plants	Unknown yellow compound
48.		Experim.	<i>Pteridium aquilinum</i> Eagle fern	No mordant, boiled	Fresh plants	Maclurin-equivalents, kaempferol, unknown flavonoids, chlorophyll-equivalents
Lichens						
49.		Folk, Hassi	<i>Cetraria islandica</i> Iceland moss	Alum + cream of tartar, boiled	Fresh lichens	Unknown yellow compounds
50.		Folk, Hassi	<i>Cladonia stellaris</i> Star-tipped reindeer lichen	No mordant, boiled	Fresh lichens	Unknown flavonoids, unknown yellow compounds
51.		Experim.	<i>Lasallia pustulata</i> Rock tripe	Fermented	Dried lichens	Orcein component, unknown lichen reds, unknown lichen blues
52.		Folk, Hassi	<i>Parmelia saxatilis</i> Crottle	No mordant, boiled	Dried lichens	UV-absorbing compounds, yellow compounds
Mushrooms						
53.		Experim.	<i>Cortinarius purpureus</i> (= <i>Cortinarius phoenicus</i> , webcap species	Alum + cream of tartar, boiled	Dried mushroom	Dermocybin, dermolutein, dermoglaucin, unknown orange compounds, unknown anthraquinones
54.		Experim.	<i>Cortinarius semisanquineus</i> Surprise webcap	Fermented, Alum + cream of tartar, boiled	Fresh mushroom	Dermocybin, emodin, unknown orange, unknown anthraquinone

Mixtures						
55.		Experim.	<i>Betula pendula</i> + <i>Indigofera tinctoria</i> Silver birch + Tropical Indigo	Fermented	Dried bark + indigo powder	Indigotin
56.		Experim.	<i>Huperzia selago</i> + <i>Rubia tinctorum</i> Fir clubmoss + Dyer's madder	Fermented fir club- moss mordant, boiled dye	Dried fir clubmoss+ dry, chopped root	Alizarin, purpurin, rubiadin, lucidin- 3-O-primeveroside, ruberytic acid
57.		Experim.	<i>Rhamnus frangula</i> + <i>Rubia tinctorum</i> Alder buckthorn + Dyer's madder	Fermented bark mordant, boiled dye	Dried bark + dry, chopped root	Alizarin, emodin, chrysophanic acid, rubidin-equivalent, emodin-equivalent, 2 unknown yellows
Other						
58.		Hassi	<i>Alum mordanted</i> <i>yarn</i>	Alum $KAl(SO_4)_2 \cdot 12H_2O$ , boiled	12 % of yarns weight	-
59.		Hassi	<i>Copper mordanted</i> <i>yarn</i>	Copper sulphate $CuSO_4 \cdot 5H_2O$ , boiled	10 % of yarns weight	-
60.		Hassi	<i>Iron mordanted</i> <i>yarn</i>	Iron sulphate, $FeSO_4$ , boiled	8 % of yarns weight	-
61.		-	<i>Alum crystals</i> $KAl(SO_4)_2 \cdot 12H_2O$	-	-	-
62.		-	<i>Sand</i>	-	-	-

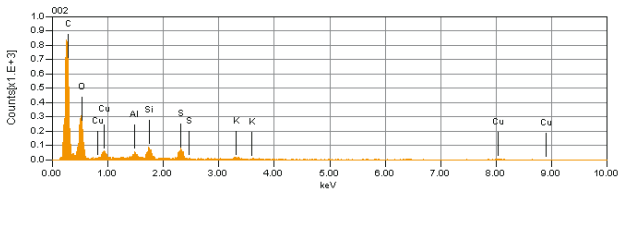
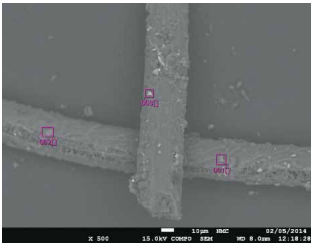
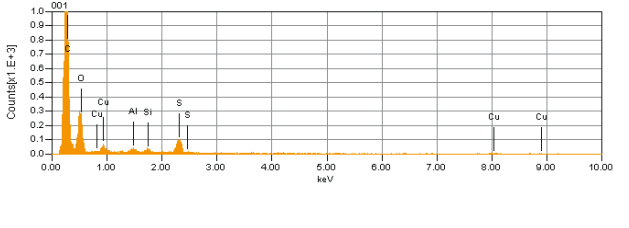
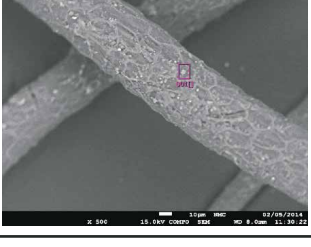
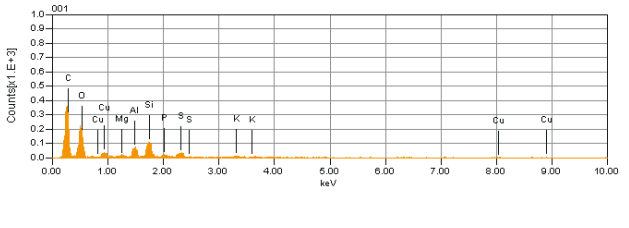
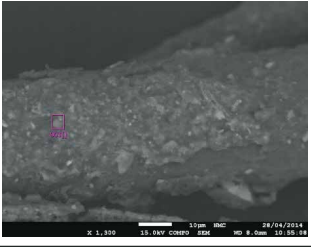
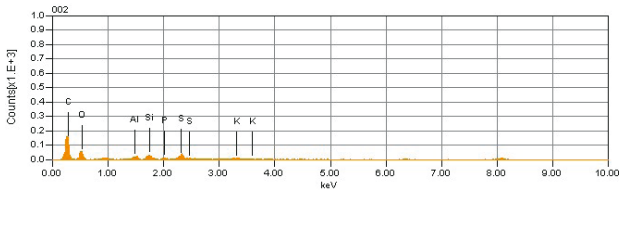
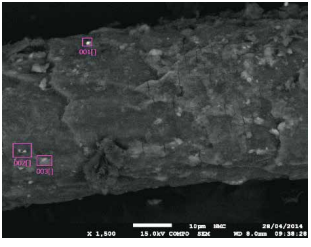
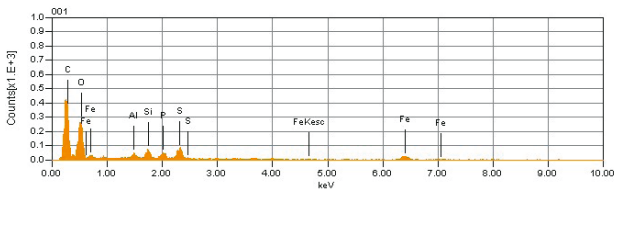

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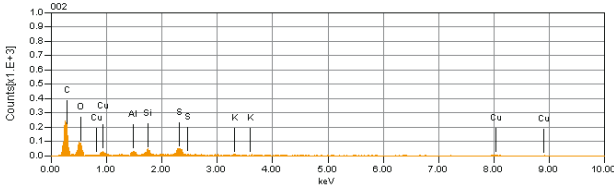
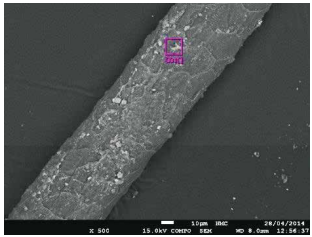
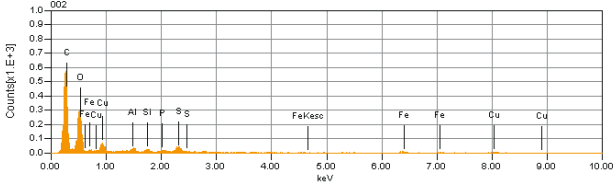
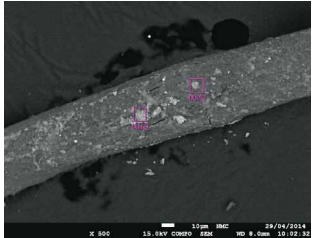
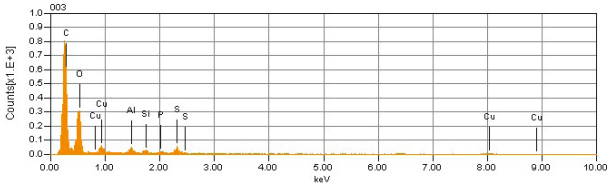
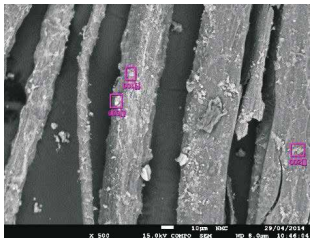
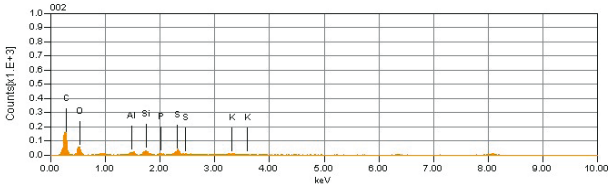
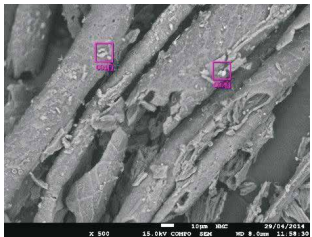
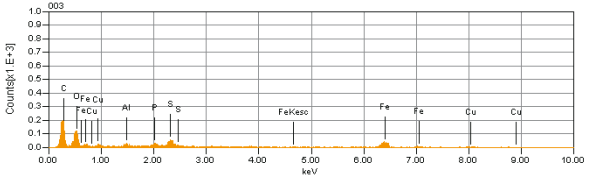
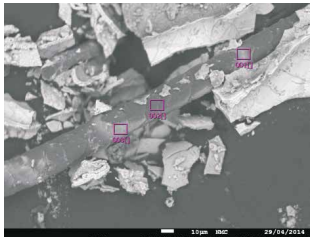
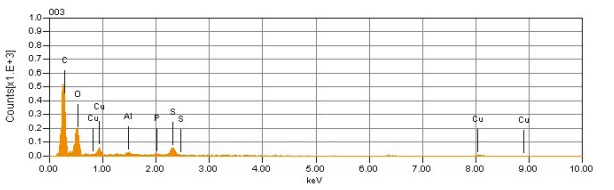
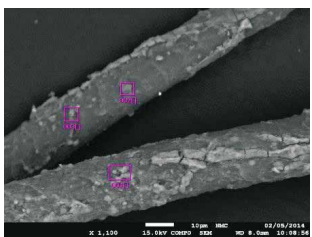
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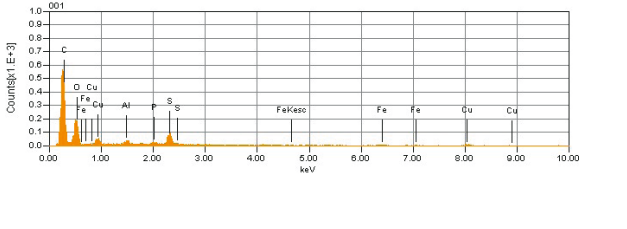
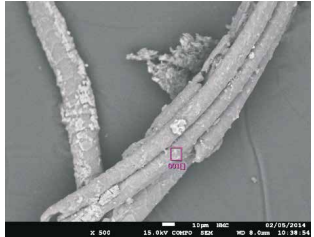
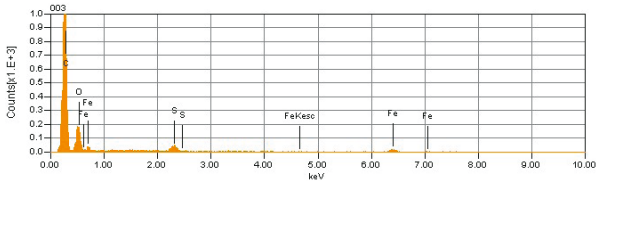
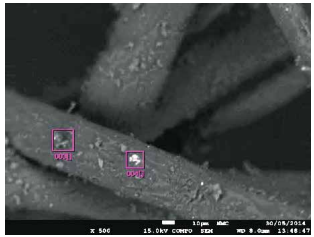
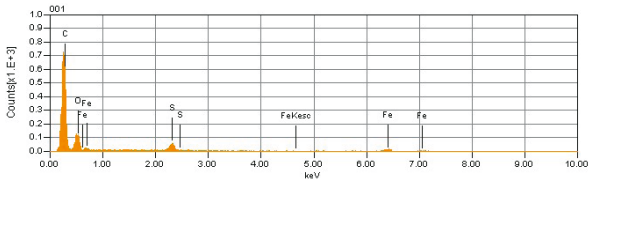
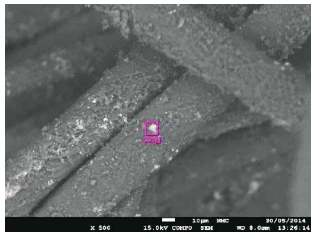
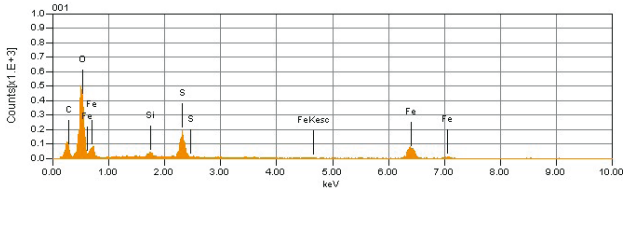

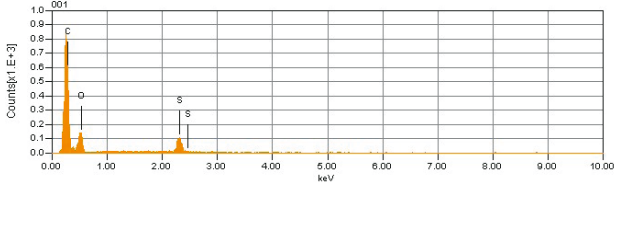
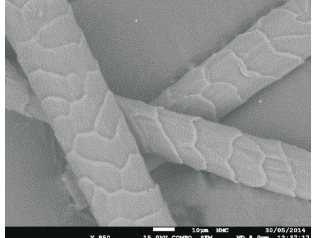
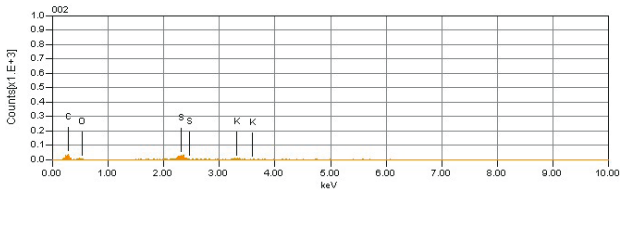
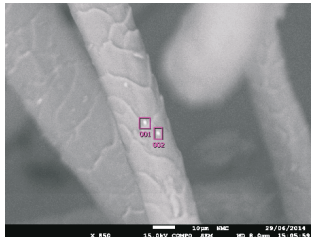
Elements of references 25, 27, 45–48 and 58–62 were analysed by K. Vajanto at the Nanomicroscopy Center of Aalto University.

Abbreviations: Folk=folklore; Experim.= experimental; Hassi and Hellen = dyeing books, see the Bibliography; Summer plant = collected at summer time during the Northern white nights; Winter = plant collected from snow during the polar winter darkness; summer stem = the stems that grow after the spring stems.

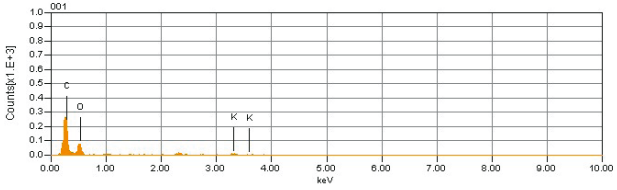
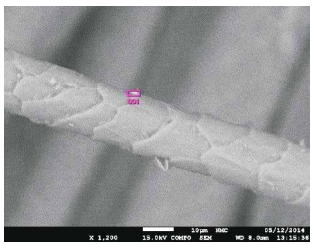
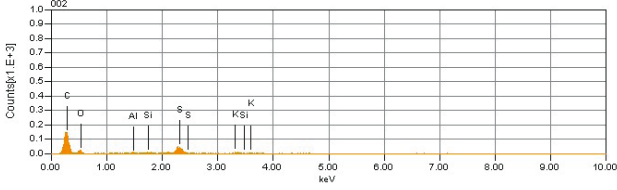
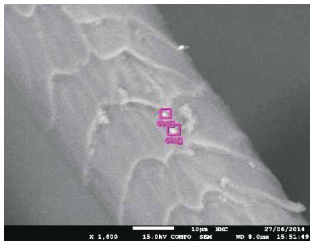
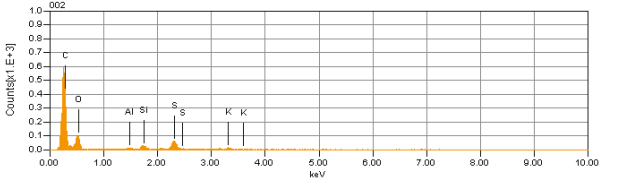
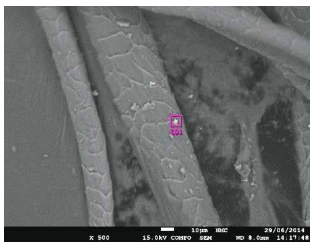
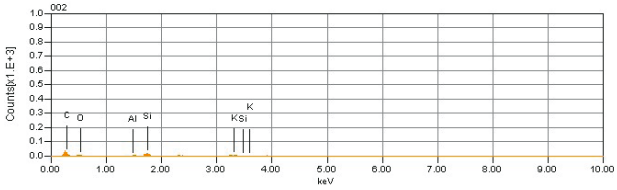
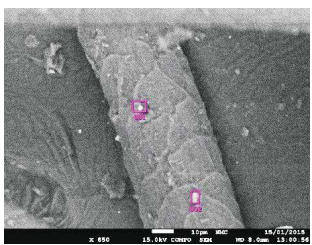
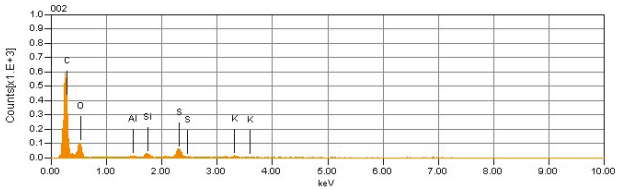
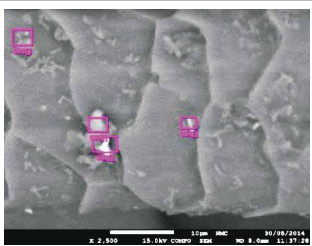
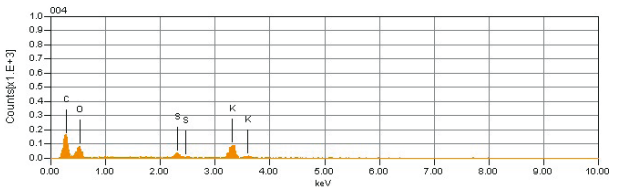
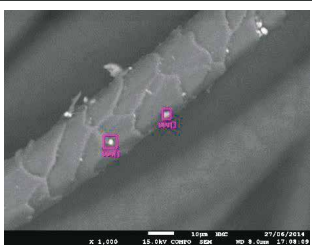
## Appendix 6: SEM-EDX results of the archaeological and reference samples

No. Sample/ Ref.	Element spectra (SEM-EDX)	SEM BSE Image
<b>1b.</b> Eura Luistari KM 18 000: 1702 red yarn		
<b>8.</b> Perniö Yliskylä KM 2912:53		
<b>9a.</b> Turku Kaarina Kirkko- mäki KM 12687: H1:20 warp		
<b>9b.</b> Turku Kaarina Kirkko- mäki 12687: H1:20 weft		
<b>10.</b> Turku Kaarina Kirkko- mäki KM 27025: H27: 168 warp		

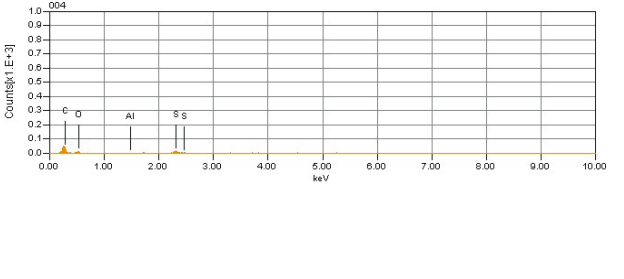
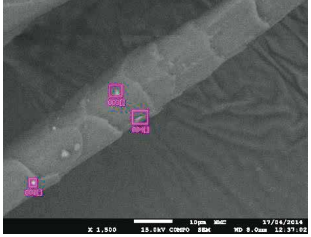
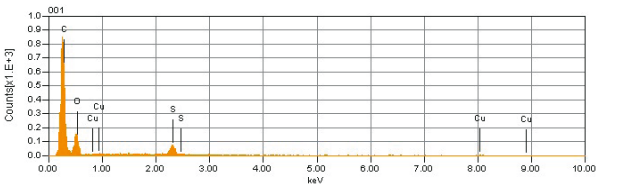

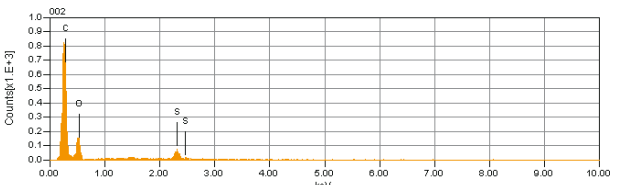
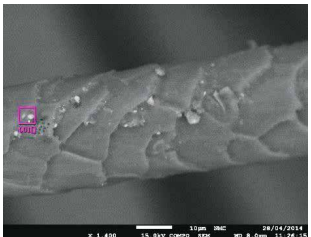
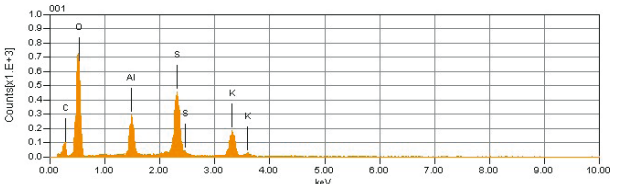
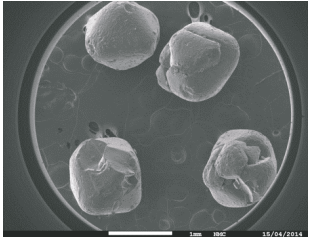
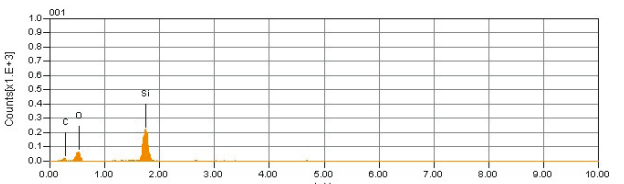
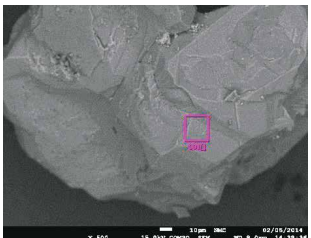
<b>11a.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:203 warp		
<b>11b.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:203 weft		
<b>12.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:230b warp		
<b>13.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:235 warp	 <p>In addition small amounts of copper (Cu) and iron (Fe).</p>	
<b>14.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:237 warp		
<b>15a.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:239 light warp	 <p>In addition small amounts of iron (Fe) and silicon (Si).</p>	

<b>15b.</b> Turku Kaarina Kirkko- mäki KM 27025: H27:239 dark warp		
<b>16a.</b> Lapuri SMM 1393:27 z yarn warp?		
<b>16b.</b> Lapuri SMM 2592:8 Sz yarn weft?		
<b>17.</b> Egelskär SMM 1657, 342006: 16		
<b>Ref. 52.</b> Crottle ( <i>Parmelia saxatilis</i> )		
<b>Ref. 25.</b> Common chickweed ( <i>Stellaria media</i> )		

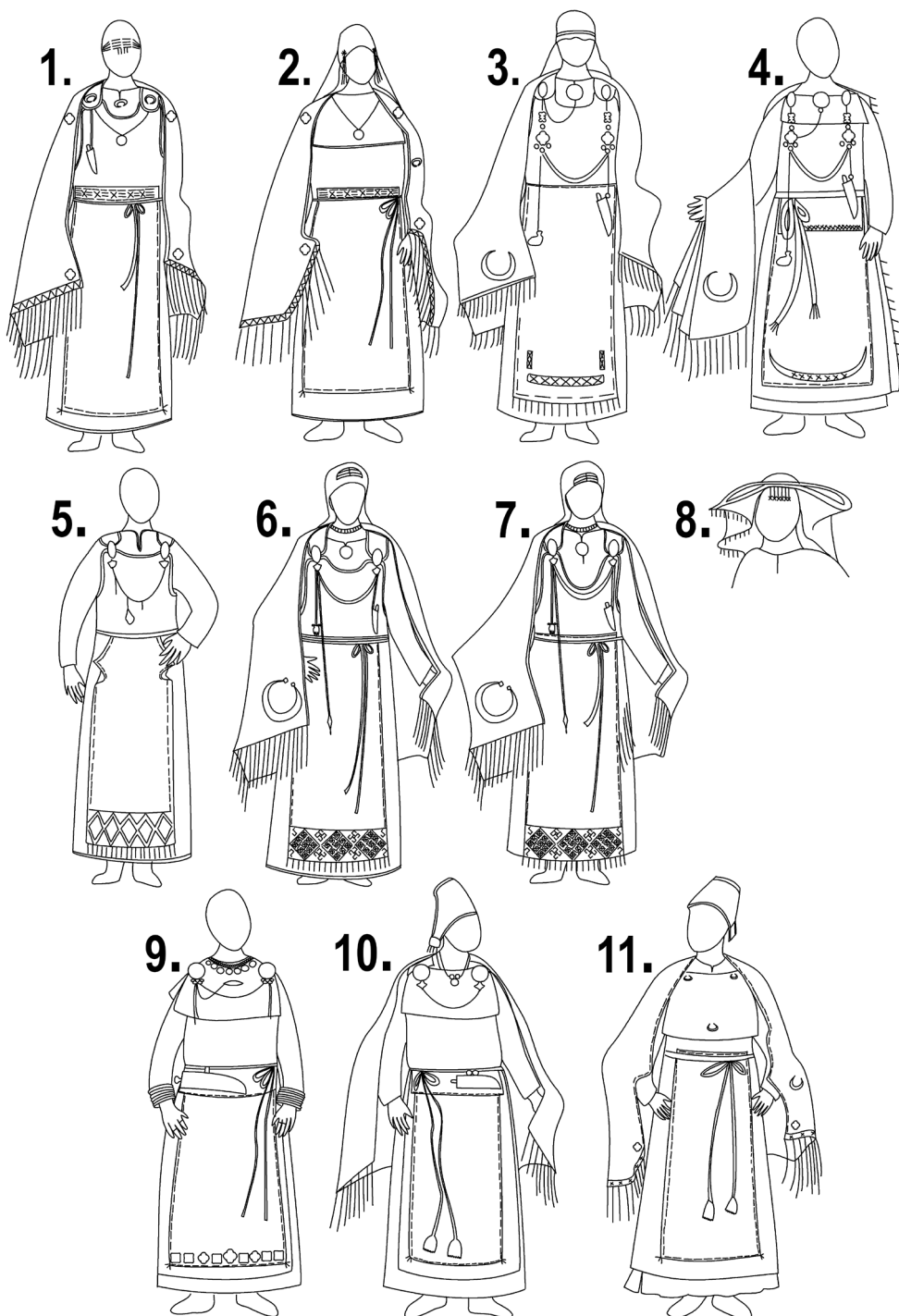


<b>Ref. 27.</b> Red sorrel ( <i>Rumex acetosella</i> )		
<b>Ref. 44.</b> Field horsetail ( <i>Equisetum arvense</i> )		
<b>Ref. 45.</b> Forest horsetail ( <i>Equisetum silvaticum</i> )		
<b>Ref. 46.</b> Fir clubmoss ( <i>Huperzia selago</i> )		
<b>Ref. 47.</b> Stiff clubmoss ( <i>Lycopodium annotinum</i> )		
<b>Ref. 48.</b> Eagle fern ( <i>Pteridium aquilinum</i> )		



<p><b>Ref. 58.</b>  Alum  <math>(\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O})</math>  mordant  (12 %)  on wool</p>		
<p><b>Ref. 59.</b>  Copper  <math>(\text{CuSO}_4 \cdot 5\text{H}_2\text{O})</math>  mordant  (10 %)  on wool</p>		
<p><b>Ref. 60.</b>  Iron  <math>(\text{FeSO}_4)</math>  mordant  (8 %)  on wool</p>		
<p><b>Ref. 61.</b>  Alum  crystals  <math>\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}</math></p>		
<p><b>Ref. 62.</b>  Sand</p>		

## Appendix 7: Costume reconstructions based on Finnish Late Iron Age finds



1: Perniö costume, 2: The new Perniö costume, 3: Tuukkala costume, 4: Mikkeli region costume, 5: Aino costume, 6: Ancient Karelian costume, 7: Kaukola costume, 8: Arc veil from Finland Proper, 9: Eura costume, 10: Kirkkomäki costume, 11: Masku costume (Drawing: K. Vajanto).

## Papers I–V

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**Paper I:** Vajanto, K. and van Bommel, M.R. 2014a. Dyed textiles from Late Iron Age Finland. *Fennoscandia Archaeologica* XXXI, 61– 78. The Archaeological Society of Finland, Helsinki.

**Paper II:** Vajanto, K. 2014. Nålbinding in Prehistoric Burials – Reinterpreting Finnish 11<sup>th</sup>–14<sup>th</sup>-century AD Textile Fragments. In A.-K. Salmi, T. Äikäs and J. Ikäheimo (eds.), *Sounds Like Theory: XII Nordic Theoretical Archaeology Group Meeting in Oulu 25.–28.4.2012. Monographs of the Archaeological Society of Finland* 2, 21–33.  
[http://www.sarks.fi/masf/masf\\_2/SLT\\_02\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_2/SLT_02_Vajanto.pdf)

**Paper III:** Vajanto, K. 2014. Finnish shipwreck textiles from the 13<sup>th</sup>– 18<sup>th</sup> centuries AD. In S. Lipkin and K. Vajanto (eds.), *Focus on Archaeological Textiles: Multidisciplinary Approaches. Monographs of the Archaeological Society of Finland* 3, 116–131.  
[http://www.sarks.fi/masf/masf\\_3/MASF3\\_09\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_3/MASF3_09_Vajanto.pdf)

**Paper IV:** Vajanto, K. 2013. Fibre Analysis of Late Iron Age, Early Modern and Modern Finnish Wools. *Fennoscandia Archaeologica* XXX, 81– 94. The Archaeological Society of Finland, Helsinki.

**Paper V:** Vajanto, K. 2014. Textile standards in experimental archaeology. In S. Lipkin and K. Vajanto (eds.), *Focus on Archaeological Textiles: Multidisciplinary Approaches. Monographs of the Archaeological Society of Finland* 3, 62– 75.  
[http://www.sarks.fi/masf/masf\\_3/MASF3\\_05\\_Vajanto.pdf](http://www.sarks.fi/masf/masf_3/MASF3_05_Vajanto.pdf)

## Krista Vajanto & Maarten R. van Bommel DYED TEXTILES FROM LATE IRON AGE FINLAND

### Abstract

This article discusses Late Iron Age archaeological dyed woollen textile fragments found in Finland from inhumation burials. The aim is to shed light on the used dyestuffs and local dyeing traditions. Most of the Iron Age fragments were woven 2/2 twill with Sz-plied in the warp and unplied z-spun yarns in the weft, which thus defines their local origin. One fragment from the very end of the local Late Iron Age was woven using plain weave and half basket weave as well as dyed with non-local dyestuffs, suggesting an imported textile. The indigoid dye was present in most of the fragments, but anthraquinones alizarin and purpurin were also found. Several unidentified red and orange components, presumably anthraquinones, possibly indicate the use of an unknown and local dye resource.

Keywords: Late Iron Age, archaeological textiles, natural dyes, dye analyses, fibre analysis, dye references, indigoids, anthraquinones, apigenin, luteolin

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### INTRODUCTION

The aim of this study is to shed light on the source and character of the dyes in the found artefacts and to trace local and imported dyestuffs in the Finnish archaeological material from the Late Iron Age (AD 800–1150/1300). Altogether 12 textile fragments with a clearly visible shade of colour were selected from five inhumation cemeteries (Fig. 1; Table 1). The samples were analysed using *High performance liquid chromatography* (HPLC) and a recently developed *Ultra High performance liquid chromatography* (UHPLC) method, both coupled to *Photo diode array detection* (PDA).

Earlier Finnish research has been done mainly thorough visual analysis to understand the structures and functions of the different textile materials to produce costume reconstructions (Lehtosalo-Hilander et al. 1982; Lehtosalo-Hilander 2001; Riikonen 2006). Fibre analysis has been done to some extent on Iron Age and Early Medieval

material (Kirjavainen 2005a&b; Kirjavainen & Riikonen 2005; 2007; Vajanto 2013a). Less than two dozen fragments from the textile rich inhumation cemeteries of Luistari in Eura, Kaarina Kirkkomäki in Turku, Tuukkala in Mikkeli and Yliskylä in Perniö have been under dye analysis (Wikström et. al. 1972; Kirjavainen & Riikonen 2005; 2007; Vajanto 2014a). Since most of these fragments were analysed using *Thin layer chromatography* (TLC) which needed large sample sizes, this protective attitude is understandable: before the development of the HPLC analysis the sample sizes were relatively large and destroyed a significant part of the researched fragment.

The Iron Age burial offerings made of bronze and copper have played an essential role in the preservation of the Finnish organic archaeological material, including textile fragments. Unlike in southern Europe, in Finland the Iron Age ended relatively late, due to the slow spread of

Christianity to the north. Therefore, the burials were still done at a relatively late date in the non-Christian tradition, i.e. with grave goods. Burial habits also played an important role: during the Late Iron Age the inhumation burials become predominant while the earlier cremation burials become less frequent (Lehtosalo-Hilander 1984a: 279–84).

## TEXTILE MATERIALS

### *Iron Age fragments from inhumation burials*

The Late Iron Age textiles are mainly of wool, because the acidic soil has caused more intensive degradation of the plant fibre textiles. The men were buried with their armoury like spears and swords, while women were interred with their tool (spindles, sickles and shears, knives) and jewellery. The female costumes consisted of a dress or a peplos dress, a square cloak, an apron, leg wraps and an undergarment. Less is known about the men's garments, because the male burials consisted of smaller amount of protective bronze (Riikonen 2011a: 209). Probably the men wore knee pants, leg wraps, a square cloak and shirt or tunic (Lehtosalo-Hilander 2001: 77–81; Tomanterä 2006: 45–6).

### *Cemetery of Luistari in Eura*

Grave 95 of the inhumation cemetery of Luistari in Eura was excavated in 1969. This female burial contained round shoulder brooches, bronze chest chains and bronze finger rings. The forms of the finds date the burial to the Viking Age, i.e. AD 800–1050 according to local chronology (Kivikoski 1973; Lehtosalo-Hilander 1982: 292, 295, 402–3). Additional finds were a clay pot, two iron knives (one at the waist, one on the neck), bronze spirals from an apron and remains of fur (Lehtosalo-Hilander 1982: 111–3).

The female had two bronze arm rings in both hands, which had preserved the studied fragments KM 18000:2071 (1.5 × 2.5 cm) and KM 18000:2084 (7 × 10 cm). These might have originated from a single textile item due to the strong similarities in the structure. The Sz/z yarns have been spun of shiny, fine-looking wool. The thread count per centimetre is 10/10. The textile is 2/2 twill which is a very common textile structure amongst the Finnish Late Iron Age material. In



Fig. 1. Sites mentioned in the text: 1. Eura Luistari, 2. Turku Kaarina Kirkkomäki, 3. Halikko Rikala, 4. Perniö Yliskylä, 5. Mikkeli Tuukkala, 6. Oulu Cathedral. Illustration: K. Vajanto.

the well-researched Luistari grave 56 the woolen undergarment was woven in tabby (Lehtosalo-Hilander et al. 1982: 25), but here the twill suggests that the fragments are not from an undergarment. Indeed, these fragments might be of a brooch fastened peplos-typed dress, which has often been found in prehistoric Finnish burials.

### *Cemetery of Yliskylä in Perniö*

Some of the best preserved fragments of a Late Iron Age female costume were excavated from the inhumation cemetery of Yliskylä in Perniö in 1893 (Appelgren-Kivalo 1907: 28–58). There are remains of square cloaks, dresses and aprons. All the material is very fragmentary, but some pieces are exceptionally large: a preserved apron has a few centimetres wide, bronze spiral ornamented selvage with a length of almost 70 centimetres; a square cloak has bronze ornamented edges with a length of c 100 centimetres (Appelgren-Kivalo

No. Find	Function	Structure	Yarns	Date (AD)
1. Eura Luistari KM 18 000:2071	Peplos dress? Cloak?	2/2 twill	Sz/z	10–11th century
2. Eura Luistari KM 18 000:2084	Peplos dress? Cloak?	2/2 twill	Sz/z	10–11th century
3. Halikko Rikala KM 12 690:168	Cloak?	2/2 twill	Sz/z	11–12th century
4. Mikkeli Tuukkala KM 9770:5	Cloak?	1/1 tabby + half basket weave	s/z	13/14th century
5. Perniö Yliskylä KM 2912:53	Dress	2/2 twill	Sz/z	11th century
6. Turku Kaarina Kirkkomäki KM 12687:H1:20	Cloak	2/2 twill	Sz/z	11th century
7. Turku Kaarina Kirkkomäki KM 27025:H27:168	Cloak II	2/2 twill	Sz/z	11th century
8. Turku Kaarina Kirkkomäki KM 27025:H27:203	Dress II	2/2 twill	Sz/z	11th century
9. Turku Kaarina Kirkkomäki KM 27025:H27:230b	Belt of apron I	Finger-woven braid	z	11th century
10. Turku Kaarina Kirkkomäki KM 27025:H27:235	Binding band of leg wraps	Braided band	z	11th century
11. Turku Kaarina Kirkkomäki KM 27025:H27:237	Belt	Tablet woven band	Sz	11th century
12. Turku Kaarina Kirkkomäki KM 27025:H27:239	Belt of apron II	Finger-woven braid	Sz	11th century

*Table 1. Overview of the samples.*

1907; plates VIII&XI).

In 1925, a reconstruction of the Perniö costume was made based on the Yliskylä materials, but by combining information from several graves. The first attempt to analyse the dyes was done in 1972 at the VTT Technical Research Centre Finland. The level of dye analysis was not very evolved at that time but indigotin was found in two fragments from graves 2 and 6 (Wikström et al. 1972).

Fragment KM 2912:53 is from grave 1 and probably belongs to a dress, which has been visually estimated to be reddish (Lehtosalo-Hilander 1984b). This fragment is 2/2 twill and woven using Sz/z yarns. The dress was made of a square fabric with shoulder seams and sewn tubular form; there is a seam in front of the dress (Appelgren-Kivalo 1907: 33–4, plate VII). The wool is shiny and the yarns very evenly spun.

### *Cemetery of Kaarina Kirkkomäki in Turku*

The Kirkkomäki inhumation cemetery in Turku (formerly part of Kaarina parish) contains several inhumation burials. Grave 1 was excavated in 1950 (Riikonen 1990; 2003; 2006) and is dated to

the early 11th century AD. This burial contained several blue textiles, including a peplos dress, an apron and a headdress (Riikonen 1990). In 2004, a sample from the square cloak of grave 1 was analysed. The warp yarn contained red tannins (Kirjavainen & Riikonen 2005: 41; Walton 2004).

Kirkkomäki grave 27 is somewhat younger than grave 1 (Kirjavainen & Riikonen 2005; 2007; Asplund & Riikonen 2007: 32), both made for females. Grave 27 was excavated in 1991, but mainly investigated in a laboratory after the field work and after being frozen for several years (Riikonen 2011b). The remains of an undergarment, two dresses, two square cloaks, two aprons, a headdress and leg wraps were found (Kirjavainen & Riikonen 2005; 2007). There was a tablet woven band at the waist area, bearing bronze bear tooth imitating pendants (Asplund 2005: 15; Riikonen 2005: 50–2). The pattern of this belt is very complicated and has been woven with blue and reddish yarns (Pennahaverinen 2009a&b). The aprons had finger-woven, diagonal braided sashes in the upper corners (Kirjavainen & Riikonen 2007: 136, 139).

The dyestuffs of some Kirkkomäki grave 27 fragments were analysed using TLC (Walton 2001a). Indigotin and red tannins were found in

the square cloak II. Dress II and square cloak II contained red-brown tannins. The dark warp yarns of the finger-woven sashes of aprons I and II contained red brown tannins, while red tannin and a trace of alizarin was found in the braided band of the leg wraps (Walton 2001a; Kirjavainen & Riikonen 2007: 135–7). The light coloured warp of the finger-woven sash of apron I contained indigotin. Two samples of the tablet woven belt both contained indigotin, but in different amounts (Penna-Haverinen 2009a: 66). The source of red tannins remained undefined, and because of this, the left over material of TLC was taken to re-analysis with the UHPLC.

### *Cemetery of Rikala in Halikko*

Fragment KM 12690:168 (3.5 x 4.5 cm) was found in female's grave 12 of the inhumation cemetery of Rikala in Halikko. The site is one of the richest Late Iron Age inhumation cemeteries in Finland. It was excavated in 1950–51 and 1953, but already before that by non-archaeologists (Mäntylä-Asplund 2011: 223). Because of this activity, the original burial context of the grave 12 was disturbed and the original position of this fragment is unknown.

The fragment is 2/2 twill and woven using 10/8 yarns per centimetre. It might be of a square cloak (Riikonen 2007: 19–20). There is an uneven striped structure created by two different weft yarns and the phenomenon is visible also in X-ray pictures (Riikonen 2007: 19). The light-coloured weft yarns (weft 1, sample 3c) have a smaller spin angle and are half of the diameter of the thicker and more tightly spun, darker weft yarns (weft 2, sample 3d). Two samples were taken from warp yarns from two different places.

### *Cemetery of Tuukkala in Mikkeli*

The cemetery of Tuukkala in Mikkeli was found in 1886 (Heikel 1886). This area with an estimated 90–100 graves has been excavated several times. The recent research dates the site to the transition of the 13th and 14th centuries AD (Mikkola 2009: 184). According to the local chronology this was the transition era of Late Iron Age and Early Medieval Period, but the burials were still done in the Iron Age style with grave offerings. Fragment KM 9770:5 (c 30 x 30) is from a male grave, found in 1933. Additional finds of the burial are a fragment made with the *nålbinding*

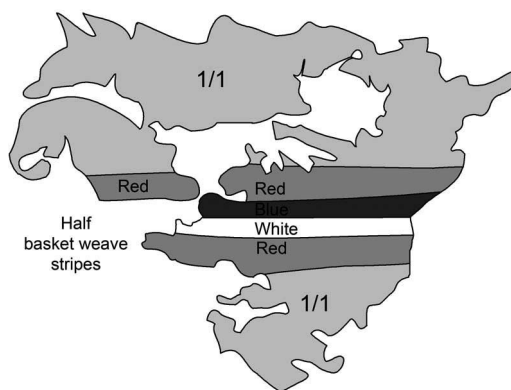


Fig. 2. Schematic map on Mikkeli Tuukkala fragment KM 9770:5. Illustration: K. Vajanto.

technique, a knife, a fire steel striker, a belt with a bronze buckle and two other wool fabrics. The textile fragment has four stripes in the middle area woven with reddish, blue and white wefts (Fig. 2). There are no traces of felting.

The striped area has been woven with half basket weave (extended plain weave) using thick and fluffy, z-twisted yarns. Otherwise the fragment is 1/1 plain weave (tabby), which has been woven with tightly spun s-yarns in warp and z-yarns in weft. The thread count is 10/10 per centimetre. The structure can be woven using a straight draft on four shafts; in which the heddling is done in the order of 1+2+3+4. When weaving, the shafts 1+3 and 2+4 are lifted in turn for a 1/1 plain weave. For the half basket weave, the shafts 1+2 and 3+4 are lifted in turn (Robinson & Marks 1973: 91–3). The striped Tuukkala fragment has been suggested to be imported (Riikonen 2007: 20) and indeed it has parallels in English 14th-century textiles (Crowfoot et al. 2006: 52–5, 64–5, plates 6–8: ray textiles) as well as in finds of Novgorod in Russia (Nahlik 1963: 232).

## DYESTUFF AND FIBRE ANALYSES

### *Basics on the natural dyes*

For natural dyes, three different dyeing procedures can be used depending on the dye molecule itself. The easiest way is the *direct dyeing* method that is used when dyeing with tannins, safflower (*Carthamus tinctorius* L.) and lichens (Cardon 2007: 4). In this method, the dye is ex-



tracted from the dye plant in (warm) water, filtered to remove the plant material and next the textile fibres or yarns or a whole textile is brought into the dye bath that is often boiled during the dyeing. The dyeing occurs via hydrophobic interaction, in which the colour producing chromophores prefer to seek the fibres rather than stay in the dye bath.

The most used dyeing method is *mordant dyeing*. In this process, the textile material is first inserted in a bath with metal salts like aluminium, iron, tin, chrome and copper (Dean 1999: 38–9). Then the metal-salt-mordanted textile material is put into the dye bath that contains dye compounds from plants. The dye compounds form a bond with the metal, which serves as a bridge between the textile fibre and the dye. The wash and light fastness of material dyed by this method is generally much better compared to direct dyes; the majority of the natural dyes are mordant dyes (Cardon 2007: 4–6).

The most complicated dyeing technique is *vat dyeing*. This is done with indigo plants and Tyrian purple. The main components of these dyes are not soluble in water; therefore, they have to be reduced into their water soluble leuco-form. Traditionally this was done using fermentation but nowadays reducing chemicals are used. The textile material is inserted into the dye bath after this reduction step and the leuco dyes are bound to the textile fibres. Once this textile is exposed to air, the dye is oxidised and forms a very stable dye bound to the textile fibre (Schweppe 1993: 282–318; Cardon 2007: 4, 337–8, 559–662).

### Methods of dye analyses

Accurate dye analysis can be only done by taking samples from the objects of interest, thereby disturbing their integrity. *Thin layer chromatography* (TLC) is still used sometimes for dye analyses because its cost effective and relatively easy protocol. The disadvantage of this method is that it needs large samples. *High performance liquid chromatography* (HPLC) analysis coupled with *Photo diode array detection* (PDA) is a very strong identification tool that requires only a very small sample, for example a few millimetres of yarn (Fig. 3). Therefore, HPLC could be described as a micro-destructive method. Recently, an advanced technique, *Ultra high performance liquid chromatography* (UHPLC-

PDA), was introduced for the analysis of natural colorants. Due to an improved separation of the components and a better resolution of the method, UHPLC-PDA is more sensitive than HPLC-PDA for which the sample size could be reduced even further (Serrano et al. 2013).

The dyestuffs of samples 1–4 were analysed using HPLC-PDA, but samples 5–12 were analysed with UHPLC-PDA. The references were analysed in the same way as the archaeological samples (Proano Gaibor 2011). Prior to analysis, the organic colorants were extracted from the textile fibres and brought into solution using a two-step extraction procedure. In the first step, an organic solvent, dimethyl sulfoxide (DMSO), was used to extract vat dyes and direct dyes by heating the sample at 80 °C for 10 minutes. Next, the DMSO fraction was separated from the sample and a second extraction was performed on the remaining sample using a solution of methanolic hydrochloric acid (HCl). This sample was heated at 100 °C for 10 minutes. During this step, also the mordant dyes can be extracted from the textile fibre. After the second extraction, the HCl was removed by evaporation under a nitrogen flow and the sample was dissolved using the DMSO from the first extraction step. After careful centrifugation to remove any remaining particles, an aliquot of the sample was introduced into the HPLC or UHPLC system.

During the (U)HPLC analysis, the organic colorants were separated from each other and their ultraviolet-visible spectra (UV-VIS) were recorded by PDA. Compounds were identified

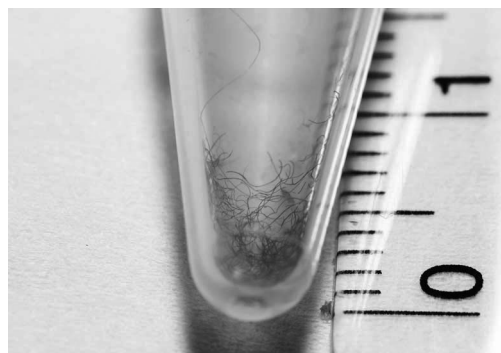


Fig. 3. Sample size of Mikkeli Tuukkala fragment KM 9770:5 red yarn was quite small. Nevertheless, several different dye compounds were detected. Photo: K. Vajanto.



by comparison of these UV-VIS spectra and their respective retention times with known reference material, which data is stored in a (U) HPLC-library. Unfortunately, identification is not always possible, due to the low concentration in the sample or a lack of reference material. However, from the UV-VIS spectra the colour of the unknown compound can be deduced unless the unknown compound is a degradation product, which has undergone a change of colour (Hofmann-de-Keijzer et al. 2013: 137–40).

### Dyed references

Due to the northern latitude, the vegetation in Finland differs from that in the southern areas of Europe and the dye plant sources have been different. Thus, several references were dyed using the local and traditionally known dye plants (Vajanto 2014b). The recipes were found in Finnish dyeing books (Kontturi 1945; Hassi 1978) as well as from folklore collected by the Finnish Literature Society. According to these, the red was dyed with bedstraws or using fermented tannins. The yellow shades came from local wild plants. The blue was either woad (*Isatis tinctoria* L.) or anthocyanin dye produced from purple flowers with clubmoss (*Lycopodium* species) as a mordant (Vajanto 2013b), a recipe that was in earlier research (Hirviluoto 1999) assumed to describe woad dyeing.

Most of the references were pre-mordanted with alum and cream of tartar and boiled with plant material: the roots of northern bedstraw (*Galium boreale* L.) and Lady's bedstraw (*Galium verum* L.), the bark of common alder (*Alnus glutinosa* L.), branches of crowberry (*Empetrum nigrum* L.), bog rosemary (*Rhododendron tomentosum*) and heather (*Calluna vulgaris* L.), spring leaves of silver birch (*Betula pendula* L.) and mushroom surprise webcap (*Cortinarius semisanguineus* Gillet). A bladder wrack (*Fucus vesiculosus* L.) bath was first fermented, and then the yarn was added and boiled with added alum. The rock tripe (*Lasallia pustulata* L.) reference was dyed in a fermented urine vat. Fermentation baths were made of water, wood ash lye and roots of common tormentil (*Potentilla erecta* L.) or the inner bark of silver birch (*Betula pendula* L.) or the bark of alder buckthorn (*Rhamnus frangula* L.) (Vajanto 2013c; 2014b).

### Wool types

Wool yarn can contain fibres from underwool, hairs from the outer coat or be homogenous depending on many parameters like the sheep breed, sheep's age and sex. Wool can be categorised by the often-used Ryder's grouping, which has been seen to follow the evolution of sheep and fleece. The wool types are named as *Mouflon type*, *Hairy* (H), *Hairy medium* (HM), *Generalised medium* (GM), *Medium* (M), *Fine/Generalised Medium* (F/GM), *Semi Fine* (SF) and *Fine* (F) (Ryder 1974; 1984; 1987; Walton-Rogers 2004: 83). This is a practical tool to see similarities and differences amongst the studied wool material. However, the Ryder's grouping does not take into the consideration the spinner's selections set for the yarn quality. This activity has probably changed the original fleece's range of fibre diameter in the finished yarn. A recently presented alternative classification is based on the textile industry (Rast-Eicher 2008; Rast-Eicher & Bender Jørgensen 2013: 1226).

The Ryder's grouping is made by measuring the diameter of 100 single fibres (Ryder 2000: 4). Samples with a length of 1–2 millimetres were cut from yarns and placed on a slide with a drop of distilled water. The fibre diameters were measured with a Leica DMLS (DFC 420) transmitted light microscope using the Leica LAS Core V 3.6 program. The fibres' medulla and pigmentation were also observed.

Most fragments were organic, but the Luistari

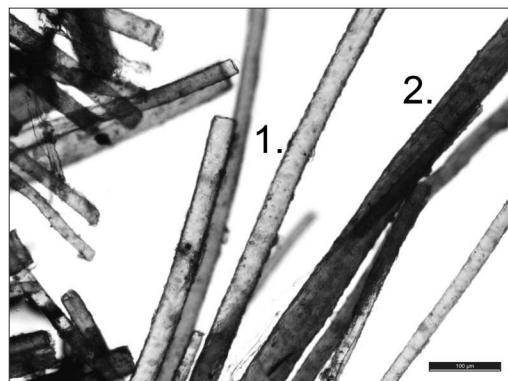


Fig. 4. Colourful, but degraded wool fibres from Eura Luistari KM 18000:2071 weft: 1. light brownish, 2. dark blue. Scale bar 100 µm. Photo: K. Vajanto.

Sample	Wool type	Count of fibres (100%)	Medullated (100%)	Pigmented (100%)	Mean (µm)	Mode (µm)	Variance	Standard deviation
1a.	HM	119	11	0	27.11	20	125	11.19
1b.	HM	87	18	0	30.45	26	167	12.92
2a.	HM/GM	114	2	0	30.7	24	96	9.81
2b.	HM	61	2	0	23.70	20	46	6.77
3a.	HM/GM	25	20	0	37.36	52	233	15.27
3b.	HM/GM	50	6	0	27.84	30	47	6.84
3c.	HM	87	3	0	27.43	20	120	10.96
3d.	HM	50	2	0	26.26	18	149	12.22
4a.	M?	5	0	0	30.8	28	16	3.97
4b.	GM/M	55	16	0	38.55	32	238	15.43
4c.	GM/M	77	0	0	27.25	26	33	5.75
5.	H?, visual analysis only							

6.–12. Discussed by Kirjavainen & Riikonen (2005; 2007): Kaarina Kirkkomäki grave 27 material contained H, HM and GM wool.

Table 2. Wool types of the researched samples.

and Rikala samples were partly mineralised and so degraded, that proper fibres for the analysis were very difficult to find (Fig. 4). In these cases, only 50 fibres were measured. It has been pointed out that this number of measurements differs statistically very little from the recommended 100 measurements (Kirjavainen 2005a&b; Kirjavainen & Riikonen 2007: 135). In addition, the Tuukkala sample 4a was very small, only a few fibres altogether. Only some fibres were measured and the remaining fibres were sent to HPLC-PDA dye analysis. However, by visual observation, it could be seen the yarn's fibre material seemed to be very homogenous throughout. The Yliskylä sample was left out of fibre analysis due to the small sample size, but in visual observations it contained very fine under-wool with some quite coarse hairs.

## RESULTS

### Fibres

The samples from Kirkkomäki, Luistari and Rikala contained *Hairy* and *Hairy medium* wool (Table 2), accompanied with *Generalised medium* and *Hairy medium/Generalised medium* intermediate wool type. The yarns in Tuukkala KM 9770:5 fragment contain *Medium/Generalised medium* and *Medium* wool.

### Dyes

The results of the dye analyses are presented in Table 3. If possible, the warp and weft yarns were

analysed separately, but the plied warps were not opened for separate analysis. The indigo dye was present in most of the samples (Table 3). This dyestuff was often found together with isatin and indirubin; the latter is a red isomer of indigotin. A trace of red purpurin dyestuff was found in the warp yarn of the Kirkkomäki sample 6b square cloak using UHPLC analysis. Sample 4a from Tuukkala contained both red dyestuffs alizarin and purpurin, but in addition, there was also a trace of indigotin present in this sample. Sample 4c from the tabby area of the Tuukkala fragment contained the yellow dyestuffs apigenin and luteolin. In addition, several unknown compounds were detected (Van Bommel 2013a&b).

## DISCUSSION

### Wool

*Hairy*, *Hairy medium*, *Generalised medium* and *Hairy medium/Generalised medium* intermediate wool types are predominant in the Finnish Late Iron Age material (Ryder 1978; Kirjavainen 2005a&b; Vajanto 2013a). In earlier research, the *Hairy*, *Hairy medium* and *Generalised medium* wool types have been defined in the Kirkkomäki grave 27 samples (Kirjavainen & Riikonen 2005: 36–7). According to these samples, the Iron Age sheep in Finland had predominantly a double coated fleece; thus exceptional fibre distributions might refer to an imported textile or a textile made for a very special purpose by carefully selected fibres. This suggests that the Tuukkala textile is imported or a special item. All the wool

No.	Sample	Indigoid dyestuffs	Red anthraquinones	Yellow and colourless components	Unknown red and orange components	Other remarks
1a.	Eura Luistari KM 18000:2071 warp	Indigotin, indirubin, isatin	-	Chrysoeriol? Unknown yellow and colourless compounds	-	-
1b.	Eura Luistari KM 18000:2071 weft	Indigotin, indirubin, isatin	-	Chrysoeriol? Unknown yellow and colourless compounds	-	-
2a.	Eura Luistari KM 18000:2084 warp	Indigotin, indirubin, isatin	-	Chrysoeriol? Unknown yellow and colourless compounds	-	-
2b.	Eura Luistari KM 18000:2084 weft	Indigotin	-	Chrysoeriol? Unknown yellow and colourless compounds	-	-
3a.	Halikko Rikala KM 12690:168a warp 1	Indigotin (trace)	-	Woad flavonoid	-	-
3b.	Halikko Rikala KM 12690:168b warp 2	Indigotin (trace)	-	Maclurin equivalent? Unknown yellow and colourless compounds	-	-
3c.	Halikko Rikala KM 12690:168c weft 1	Indigotin (trace)	-	Unknown yellow and colourless compounds	-	-
3d.	Halikko Rikala KM 12690:168c weft 2	Indigotin (trace)	-	Unknown yellow and colourless compounds	-	-
4a.	Mikkeli Tuukkala KM 9770:5 red weft	Indigotin (trace)	Alizarin, purpurin, rubiadin, unknown anthraquinone	-	-	-
4b.	Mikkeli Tuukkala KM 9770:5 beige weft	-	-	Unknown yellow and colourless compounds	-	Possibly undyed
4c.	Mikkeli Tuukkala KM 9770:5 brown warp and weft from tabby	-	Alizarin (trace), purpurin (trace), unknown anthraquinone	Luteolin (trace), apigenin (trace), unknown flavonoid	-	-
5. (*)	Perniö Yiskylä KM 2912:53 warp	Indigotin, indirubin, isatin equivalent, isatin	-	-	Red (498 nm/ 18.22 min), red-orange	Very rich in blue dye
6a. (*)	Turku Kaarina Kirkkomäki KM 12687:H1:20 warp	Isatin (trace)	-	-	Orange (385nm/ 15.96min)	-
6b. (*)	Turku Kaarina Kirkkomäki KM 12687:H1:20 weft	Indigotin, Indirubin, Isatin (trace)	Purpurin	-	Red 468 nm/16.11 min), red-orange	Unknown red or blue components (traces)
7. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:168 warp	indigotin, indirubin, isatin	-	-	Red-orange (429 nm/ 19.60min)	-
8a. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:203 warp	Indigotin, indirubin (trace), isatin (trace)	-	-	Red-orange (429/19.60 min) and red	-
8b. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:203 weft	Indigotin (trace), indirubin (trace), isatin	-	-	Red-oranges (429nm/ 19.60 min), reds and oranges	Unknown reddish component from woad?
9. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:230b warp	Isatin?	-	Traces of unknown yellow components	Red-orange (429nm/ 19.60 min)	-
10. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:235 warp	-	-	Unknown yellow components	Red-orange (429nm/ 19.60 min)	-
11. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:237 warp	-	-	Unknown yellow components	Red-orange (429nm/ 19.60 min)	-
12a. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:239 warp, light yarn	Indigotin, indirubin (trace), isatin	-	-	-	-
12b. (*)	Turku Kaarina Kirkkomäki KM 27025:H27:239 warp, dark yarn	Indigotin	-	-	Red-oranges	Diamond green B, unknown synthetic red

Table 3. The HPLC-PDA and UHPLC-PDA (\*) results. The KM-number refers to the archaeological collections of the National Museum of Finland.

samples seemed to contain unpigmented wool. However, since all of the fibres were more or less colourful due to dyeing, defining the wool's natural colour was difficult.

### *Indigoid dyestuffs and their sources*

Indigotin is one of most stable natural dyes and the only natural dye that can give a stable blue colour. Because of this good permanence, it is no wonder that indigotin was found in most of the analysed samples (see Table 3). The presence of indigotin, isatin and indirubin indicates the use of woad or indigo (*Indigofera tinctoria* L.), which are the two indigoid plant species mainly used in Europe. However, it is impossible to identify the particular indigoid plant via dye analysis as all indigoid plants contain the same principle components.

An especially skilled dyer has been dyeing the Yliskylä yarn, which contained a very rich amount of dyestuff (Table 3, sample 5). In the Kirkkomäki sample 8b, the ratio between indigotin and indirubin was abnormal: it differed from the sample 8a that got the normal ratio (Table 3). This might refer to two different indigo dyeing recipes. Unfortunately, it is unknown, which of many indigo dyeing recipes was used in Iron Age Finland, but the folklore survey data from the early 20th century contains knowledge of woad balls and vat dyeing method with old urine.<sup>1</sup> An explanation for the different ratios might be that one vat was prepared using frost bitten and thus indigo-poor woad leaves during early summer (or late autumn) and the second vat was made with indigo-rich leaves during midsummer.

In Early Modern Finland, woollen folk textiles were dyed with either woad or tropical indigo to produce evenly blue or patterned, ikat-dyed *flammu* yarns (Lehtinen & Sihvo 2005: 24–5). The striped *flammu* yarns were dyed by tying the skeins around a special wooden stick, a *lamupuu*, with indentations (Vuorela 1977: 496–7). No evidence of this craft is found in the Iron Age blue textiles. These were probably dyed either as yarns or as whole garments; the undyed parts in the plied yarns in Yliskylä and Luistari textiles suggest that.

In Finland woad grows on the southern coast as a wild plant, mostly in the maritime environment on sandy shores on bladder wrack banks (Fig. 5) and was it even cultivated in small quan-

ties in peasant gardens (Linnilä et al. 2002: III, 63–4). The oldest Finnish archaeological seeds of woad have been found in the Early Iron Age Ketohaka 1 settlement in Salo (Aalto 1982: 141). The site was inhabited from the Pre-Roman Iron Age to the beginning of the Viking Age, i.e. 500 BC – AD 800 (Schauman-Lönnqvist et al. 1986: 91–4). However, the seeds do not indicate necessarily presence of the craft of woad dyeing. In southern Europe and amongst the Arabs woad was known as a medical and antiseptic plant (Balfour-Paul 2011: 218–9). In addition, it was used as body paint by the Gaul warriors and women (Plin. NH, XXII: 2).

Woad was cultivated in Medieval Europe in large quantities (Cardon 2007: 376–8), but the history of blue goes far back in time: blue colorant probably from woad has been found in textile materials from Neolithic Adouste cave in France and from Bronze and Iron Age salt mines in Austria (Cardon 2007: 374–5; Hofmann-de-Keijzer et al. 2013: 135–62) as well as from textiles of a Celtic princely burial of Eberdingen-Hochdorf (Banck-Burghess 2012: 145). Blue garments were known in Scandinavia already during the Early Iron Age, when the Lønne Hede girl was buried (Bender-Jørgensen & Walton 1986; Mannering et al. 2012: 110). The Swedish Högöm male burial from the Migration Period (AD 400–600) contained textiles dyed with the insect dye Polish cochineal (*Porphyrophora polonica*), weld (*Reseda luteola* L.), Dyer's madder and indigotin (Nockert 1991: 72–5). In addition, seeds of woad were found in the famous Norwegian Oseberg ship burial of Queen Åsa, dated to the early 9th century AD (Christensen et al. 1992: 222).

Tropical indigo pigment was known as a painting pigment in the Roman world already in the 1st century BC (Vitr. VII: 14). It was also known Italy in the 12th century AD, when it began its competition with woad as the main source of blue dye (Cardon 2007: 364). The import of the tropical indigo pigment was strictly forbidden in many countries from the 16th to the late 18th centuries AD, but the regulations were also broken (Cardon 2007: 376–7; Balfour-Paul 2011: 55–7) and eventually woad was replaced by indigo. However, there were routes from Scandinavia to the Black Sea and Byzantine Empire already during the Viking Ages. It is not impossible, that tropical indigo was a trade article



Fig. 5. Woad growing at seashore in Espoo, Finland. Photo: K. Vajanto.

already during that time at the Vikings' Eastern Route (Vajanto 2014a: 97). As an easily transportable, high-price product it might have been an ideal trade item (Peets 1998: 306).

### *Red anthraquinone dyes of plants*

Dyer's madder contains many different anthraquinones, of which alizarin and pseudo-purpurin are the main compounds. The pseudo-purpurin is converted into purpurin during the HCl extraction, but this does not alter the identification of the dye plants. The Finnish bedstraws have mostly pseudo-purpurin and only a little alizarin (Proano Gaibor 2011), while in Dyer's madder the ratio is the opposite (Cardon 2007: 112, 127). Accordingly, the purpurin in Kirkkomäki sample 6b might be from bedstraws (Table 3). In addition to these plant sources, the mushrooms of the genus *Cortinarius* contain other anthraquinones, mainly emodin and dermocybine.

According to folklore, the Finns dyed red with northern and Lady's bedstraw. The yarns were mordanted in a fermented clubmoss bath<sup>2</sup> or pre-dyed with birch leaves (Linnilä et al. 2002: II, 261). All bedstraws, even smaller species, were collected to the dye bath, sometimes with roots of common tormentil.<sup>3</sup> However, it is possible that the folk beliefs held that the Lady's bedstraw was the most valuable. It was believed to be good for milk and cheese production as well as a remedy for female diseases, epilepsy and heart problems. The scenting yellow flowers were laid to coffins below the deceased (Linnilä et al. 2002: II, 263). Possibly the peasant Finns were aware of the Dyer's madder, since the Finnish word for bedstraw is *matara*. This is close to the English word *madder* (i.e. Dyer's

madder) and its variants in several other languages (Chenciner 2000: 21). Moreover, the red dye was greatly valued and a specialised tool, *matarakokka*, a bedstraw hoe, was developed to collect the narrow bedstraw roots<sup>4</sup> to achieve the bright red dye from local sources.

Sample 4a from Tuukkala contained both alizarin and purpurin, suggesting the use of Dyer's madder (Table 3). The sample also contained a trace of indigotin, a possible cross-contamination of the blue stripe next to the red stripe; it could be that the small blue dyed fibres have contaminated the red yarns. The ratio between alizarin and purpurin did not correspond with the ratio normally found in Dyer's madder. This could indicate the degradation of the dyestuffs or a specific dyeing technique or a dye mixture made of Dyer's madder and bedstraws. In general, alizarin and purpurin are rare dyestuffs in the Finnish Iron Age material. Previously these have been found in Luistari KM 18000:1696 *nålbinding* fragment (Vanden Berghe 2012; van Bommel 2013a). In addition, alizarin and red tannin were found in a leg wrap band from Kirkkomäki grave 27 (Kirjavainen & Riikonen 2007: 135–7; Walton 2001a).

Dyer's madder is not native in Finland, so the Tuukkala textile, or the red weft yarn or the dye was probably imported. During the Middle Ages, Dyer's madder was the predominant source of red dye in Europe, while in France it had been cultivated at least from the 9th century AD (Chenciner 2000: 44). Dyer's madder and bedstraw dyestuffs have been detected in TLC analyses in Finnish Medieval archaeological textiles of local and foreign origin (Kirjavainen 2002: 348; 2004). Probably it was especially the professional dyers in urban centres, who used the Dyer's madder and woad in dyeing (Kirjavainen



2002: 348). Overall, the use of Dyer's madder and bedstraws seem to be more typical to the Finnish Medieval Period than the Late Iron Age.

### *Yellow dyestuffs from weeds and shrubs*

Sample 4c was from the tabby area of the Tuukkala fragment (Table 3). The dye analysis detected luteolin and apigenin, but at a low concentration level. The specific markers for dyer's broom and sawwort were not detected, but this could be due to the low concentration. Since no other samples from this textile contained these compounds, it is likely that these dyestuffs were intentionally used to dye this specific yarn to yellow. Luteolin and apigenin are present as the main components in weld (*Reseda luteola* L.), dyer's broom (*Genista tinctoria* L.), sawwort (*Serratula tinctoria* L.), dandelion (*Taraxacum officinale* L.) and yarrow (*Achillea millefolium* L.) (Hofmann-de-Keijzer et al. 2013: 153). These compounds have been detected in several peat bog Scandinavian materials dated to the Early Iron Age and Migration Period (Vanden Berghe et al. 2009; 2010), but not in the Finnish material.

Weld, dyer's broom and sawwort have been traditional dye plants in southern Europe and weld was even grown there for dyers (Cardon 2007: 169–80). In Finland, the cold winters prevent the cultivation of these biennial plants, of which the harvest is collected during the second year of growth. However, recently a tiny occurrence of sawwort was found in south-western Finland. It has been speculated whether this group of plants is recent or even of archaeophytic origin, which would mean that it might have been introduced to Finland during the prehistoric time (Alho et al. 2012).

In Finland, yellow dyes traditionally came from local wild plants that were freely available according to local rights to utilise natural resources. However, not all plants were collected for dye baths. For example, dandelion was mainly known as an edible herb and medicinal plant (Linnilä et al. 2002: II, 252). Yarrow had the same aspects, but it was also known as a source of yellow dye, especially when boiled with wood ash lye (Linnilä et al. 2002: II, 206).

Samples from Luistari contained a low concentration of a luteolin equivalent that matched with chrysoeriol (Table 3, samples 1a, 1b, 2a, 2b). This is present as a minor component in several plants,

in tansy (*Tanacetum vulgare* L.) for example. However, in all these plants the luteolin and apigenin are the main components (Schweppe 1993: 322, 352). Since luteolin was not found, it is not clear if this yellow component represents a dye. Chrysoeriol is the main component in Holy herbs (*Eriodictyon* species) of the *Boraginaceae* family (Schweppe 1993: 356), but these plants are native to North America and Mexico and are therefore excluded. The yellow component might be a degradation product or originate from the archaeological context of an unknown plant material.

All Rikala samples contained traces of indigotin, but also several unknown yellows and a woad related flavonoid in the weft 1 (Sample 3a, 3b, 3c, 3d, Table 3). This dye combination has possibly produced a greenish tint on the textile. In Finland, the traditional yellows and oranges with a good light fastness came from the spring leaves of silver birch, bog rosemary, crowberry and heather. These have rutin and quercetin as the main dye components (Proano Gaibor 2011). These dyestuffs are absent in all the analysed fragments, which raises the question whether these yellow yielding plants were used at all as a mordant dye in Iron Age Finland or perhaps the dyestuffs have just degraded completely.

### *Unknown colouring components*

There are several cases in the European textile research, in which unknown dyestuffs have been detected. There are unknown yellow and red-orange components in the Hallstatt textiles and Scandinavian peat bog textiles (Bender-Jørgensen & Walton 1986; Walton 1988; Vanden Berghe et al. 2009: 1918; 2010; Hofmann-de-Keijzer et al. 2013: 160–1). An unidentified dye called yellow-X has been detected in TLC analyses in Scandinavian and Finnish textiles (Walton 1988; 2001b.) Several unknown yellow and colourless compounds in the Luistari and Rikala samples as well as the Tuukkala sample 4b might be present due to contamination of the buried or the burial environment (Table 3).

An unknown red component was found in the Kirkkomäki sample 6b at 16.11 minutes with an absorption maximum of 468 nm (Fig. 6; Table 3). The same component has been found in three Early Modern samples from Oulu Cathedral (Lipkin et al. forthcoming). In these samples, several other unknown red and orange components were

detected that are probably related to the component labelled 'Unknown-red-468nm'. This component could indicate the use of one or maybe several local dye plants. In addition, an unknown red or orange component was found in samples 7, 8a, 8b, 9a, 9b, 10, 11 eluting at 19.60 minutes, with an absorption maximum of 429 nm (Fig. 7; Table 3). This component showed a very typical spectrum, but could not be related to any dye class known. In addition, this component could indicate a local dye species.

Many unknown dyestuffs, presumably anthraquinones, correlated with the samples in which red tannins were found using TLC analyses (Walton 2001a; 2004). This situation suggests that the TLC analysis detected these same compounds, but it must be noted that with the (U)HPLC system used no specific markers could be found for red tannins. However, the UHPLC analysis was not able to solve the mystery of these dyestuffs despite several reference yarns. For example, the reference dyed with mushroom surprise webcap showed the presence of emodin and equivalents as the main components, but since these are lacking in the analysed samples this dye source can be excluded. However, there might still be mushrooms that do not produce emodin and are not present in the reference library. Late Iron Age flora was different from modern flora and today it is difficult to find certain old dye plants for reference dyeing, such as the common corn gromwell (*Lithospermum arvense* L.) that was typical in the Medieval environment (Lempiäinen 1999: 122). Thus, the tested references possibly do not reflect the total dye plant stock that was available in prehistoric Finland.

### Contamination sources

An inhumation burial has many possible sources of dye contamination that may cause false-positive results. The results of the dye analyses represent the dyestuffs only in a very small area of the textile fragment. In the Tuukkala sample 4b no dye was detected (Table 3), suggesting that the yarn has possibly been truly undyed or the sample amount was insufficient. Even the same yarn, but different parts, can give different results. For example, the earlier TLC analysis (Walton 2001a) found a trace of alizarin from the Kirkkomäki leg wrap's band, but the UHPLC gave a negative result. In addition, in theory, the trace of

alizarin as well as the negative result might both be caused by the migration of the dyestuffs, although this is still to be proven.

The female in Kirkkomäki grave 1 was buried with newly cut barley in her hands and moss and fur layers under her (Riikonen 2003). Quite similar additions were found in the Kirkkomäki grave 27 which contained moss, fur and a wooden coffin (Kirjavainen & Riikonen 2005: 34; 2007: 135). All these grave goods could in a theory yield colouring compounds to burial textiles. The plant offerings and moss may contain flavonoids and tannins, and the furs might have been tanned with tree bark. Moreover, there have likely been plants growing above the burial for centuries. It is difficult to estimate the leak of colorants, their role in the soil and respectively in the archaeological textiles. Attempts at systematic macrofossil and pollen sampling both inside and outside the burial have been applied in textile research recently in Spain (Llargo et al. 2013) and that technique would also be useful for the Finnish research.

In Finland, there is frost in the ground four months in a year every winter. In the experiments done by the Finnish dyers and the author, it has been found, that some red dyestuffs turn brighter and pinker, if frozen first (Tetri 2008: 49). An Iron Age textile that has been buried for one thousand years has been subject to frost and frost-free periods so many times, that this might have affected somehow the organic dyes. Unfortunately, it is unknown, how these repetitive changes in the burial environment have affected the degradation rate of the dyestuffs.

In addition to organic compounds, a synthetic dyestuff Diamond green was found in the Kirkkomäki sample 12b (Table 3). This synthetic dye is also known as Malachite green, but unlike mineral malachite, this dye contains no copper. It was developed in 1877 by O. Fischer and is still produced (Schweppe 1993: 625). Because of this finding, sample 12b was examined with a scanning electron microscope (JEOL 5910 LV) coupled to an Energy Dispersive X-ray Spectrometer (SEM-EDX), which revealed partly degraded and slightly contaminated wool fibres. Therefore, the fibres were much older than the dyestuff detected. In this case, the indigoid dyestuffs and the unknown oranges are from the Iron Age. The synthetic dye was most probably a result of modern contamination.

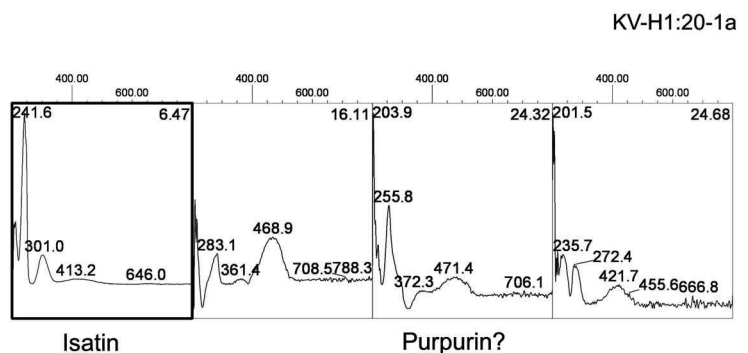


Fig. 6. Spectrum of sample 6b. Illustration: M. van Bommel.

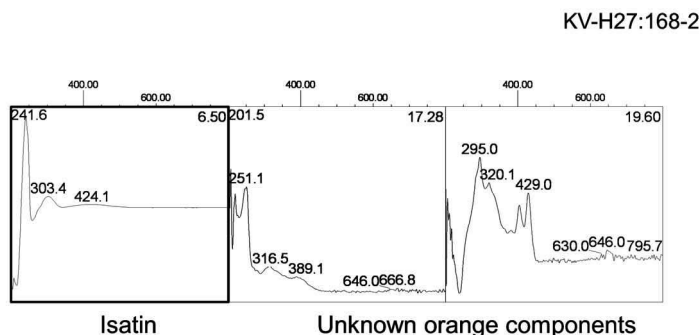


Fig. 7. Spectrum of sample 7. Illustration: M. van Bommel

It is difficult to know how the age of the textiles, the different excavation methods and the idle-time between the excavation and the dyes analysis affect the organic compounds. Possibly the excavation made in a laboratory environment, as well as the relatively rapidly carried out dye analyses, might detect the dyestuffs better. This could explain the several different dye compounds found in the Kirkkomäki grave 27 samples, which were excavated in the laboratory. Indigoid dyestuffs were the only findings in the Luistari, Rikala and Yliskylä fragments; these were also amongst the oldest textiles by date and excavated in the field. Perhaps the time spent in both the ground and the museum destroys dyestuffs; the mordant dyes faster than the indigoids.

## CONCLUSIONS

A typical Finnish Iron Age textile type, 2/2 twill made of Sz/z yarns, as well as the period-typical double coated wool suggest strongly, that the textile fragments from Kirkkomäki, Rikala, Yliskylä and Luistari are of local origin and contain local dyestuffs but the source for red remained undefined. However, the Late Iron Age red dye came from different sources than the Finnish Medieval Period red: Dyer's madder and bedstraw

reds predominated in the Medieval Finnish and the contemporary European material. The presence of purpurin in the Kirkkomäki sample 6b, KM 12687:H1:20 indicates that bedstraws were rarely used with the unknown red-yielding local plants.

The analyses made with HPLC-PDA and UHPLC-PDA gave interesting results without harming the original textile fragments remarkably. In all cases, the sample sizes were very small, less than one centimetre of yarn. Several different dye compounds were found, but indigoid dyestuffs were the most often detected. This does not indicate that blue garments would have been the Iron Age's main fashion; indigo pigment is just one of the most stabile natural dyes and thus likely has been preserved when other dyestuffs have vanished.

The presence of Dyer's madder and weld in the striped Tuukkala textile is an exceptional finding amongst the Finnish prehistoric textiles. These dye plants were not spread or have been cultivated in Finland. The unusual textile structure, exceptional fibre diameter distribution, and presence of non-local dyes suggest an imported textile product. This item represents dyeing craft of the international Medieval world rather than the local Iron Age dye traditions.



Some of the unknown red and red-orange dyestuffs correlated to the red tannins that were found in earlier TLC analyses (Walton 2001a; 2004). The unknown dyestuffs might refer to the use of still unknown local dye sources or an undefined natural mordant, degraded products of dyestuffs, or contamination of the burial environment or from the deceased. Currently, the reference material of the northern dye plants is quite wide, but still there might be plants, mushrooms or lichens that are not included to the database.

## NOTES

<sup>1</sup> SKS / KRA. Pielavesi. Tiitinen, M. 9. 3186. 1937; SKS / KRA. Korpilahti. Hyvärinen. i, k, e: 2691–2692. 1945.

<sup>2</sup> SKS / KRA. Kirvu. Pärssinen. E 142: 14–16. 1938; SKS / KRA. Rautu. Snellman. E 134: 6–7. 1936.

<sup>3</sup> SKS / KRA. Kirvu. Pärssinen. E 142: 14–16. 1938; SKS / KRA. Inkeri. Mannonen. 12 d, hi, j, s: 4409. 1937.

<sup>4</sup> NBA / Ethnographic archive. Photograph of a bedstraw hoe from Karelia, Räisälä.

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National Board of Antiquities (NBA) / Ethnographic archives:

NBA / Ethnographic archive. Photograph of a bedstraw hoe from Karelia, Räisälä. C12, L 2607, Dia 26075.

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# *Nålbinding* in Prehistoric Burials – Reinterpreting Finnish 11th–14th-century AD Textile Fragments

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**ABSTRACT** This article discusses Finnish prehistoric, woollen textiles made with the *nålbinding* technique. These textiles are from Late Iron Age inhumation burials and dated to the 11th to 14th centuries AD. A case study is made of the *nålbound* Eura Luistari fragments. These results are discussed in connection with the data related to other Finnish *nålbinding* fragments and material obtained from a survey done in 1957 concerning the *nålbinding* technique. The double spiral technique is suggested to explain the structure of the striped area in the Eura Luistari fragments. This explanation seems to exclude the presence of a thumb structure and casts doubts on the earlier mitten interpretation. It is suggested, in general, that due to the absence of a thumb, the prehistoric *nålbound* fragments might have been some kind of pouches.

## KEYWORDS

*nålbinding*, Late Iron Age, burial textiles, experimental archaeology, dyed wool, folklore

## Introduction

In Finland, the Iron Age ended mainly in the middle of the 12th century AD, in Eastern Finland ca. 1300 AD (Kivikoski 1973:10). There are inhumation graves dated to the Late Iron Age containing different types of grave goods, like bronze jewellery, ceramics, iron tools, and textiles, as well as fragments of *nålbinding* (Table 1). These *nålbound* fragments have been dated to the 11th–14th centuries AD and were found in the middle part of the grave where the deceased has been in a supine position. The fragments have often been located near the finger or hand bones, in connection to bronze rings and/or a bronze knife sheath or other bronze objects (Schwindt 1893:116–120, Plate 45; Lehtosalo-Hilander 1982:89–93; Riikonen 2003:233, 240, Plate 28). Only one *nålbound* fragment has been found

near a foot bone (Luoto & Fischer 1989:49; Riikonen 2006:15).

The earlier research, which explains archaeological fragments of *nålbinding* as mittens or socks based on the ethnographic material (Kaukonen 1960; Vahter 1934), is reconsidered here. The data obtained from Finnish prehistoric *nålbinding* fragments, folklore, and ethnographic materials is compared. The question is raised of whether the ethnographic and prehistoric material groups can be compared. Are there hidden but important elemental differences that should be taken into consideration in comparing prehistoric textile materials with modern ones, despite the many obvious similarities?



## Research history

### Nålbinding in textile history

In research, the nålbinding technique has been given many names, like knotless netting and looping (Seiler-Baldinger 1994:17; Gleba & Mannering 2012:11–12), in Finnish *neulakinnastekniikka*. The nålbinding technique has had many variants (Collin 1917; Davidson 1935; Nordland 1961; Steffensen 1976; Brodén 1978; Westman 1983; Hansen 1990; Seiler-Baldinger 1994:17; Böttcher 2001; Claßen-Büttner 2012), but has often been mentioned only as an interesting curiosity within the art of handicrafts (Rutt 1987:8–9; Barber 1991:182–183; Turnau 1991:13–15).

The oldest textiles made with the nålbinding technique are a bast fibre net from the Late Mesolithic (4200 BC) Tybrind Vig, Denmark (Bender Jørgensen 1992:115, 159–160), and textiles of a plant material from Bolkilde (Denmark, 3400 BC) and Tustrup Mose (early Neolithic, Denmark) (Mannering *et al.* 2012:94–95). In these finds the looping is quite simple. Relative stitches can be found in a woollen hat from the Tarim basin dated to 1000 BC (Barber 1999:32–33) and in sandal socks from Egypt dated to the 1st–5th centuries AD (Rutt 1987:28–31; De Moor *et al.* 2008:74, 130–131).

From the 10th to 16th centuries AD, there are woollen mittens from Middle and Northern Europe, a sock from England, a glove from Latvia, and fragments from Estonia (Arbman & Strömberg 1934; Nordland 1961:43; Zarina 1968; 1988; 1998; Caune & Zarina 1980; Peets 1987; Walton 1987; 1989; Østergård 1991; Nockert & Possnert 2002). There is also a golden nålbound lace fragment found in 10th-century-AD Mammen, Denmark (Hansen 1991). In these finds, the stitching resembles a more or less never-ending spiral, with differences in loop count and row fastening.

In Finland, the nålbinding technique was a part of living folk tradition until the middle of the 20th century, after which it was known only by textile enthusiasts. The technique was traditionally used for woollen mittens and socks, sometimes also for caps (Vahter 1934; Kaukonen 1960:46–49). Winter-fishing mittens, *jouhikkaat*, were made of pig or horse hair, and milk sieves were made of horse hair (Kaukonen

1960:46–49). There are possible woollen sock fragments from the 17th century from Oulu Cathedral, with straps to fasten them to knee pants (Kuokkanen & Lipkin 2011:153–158; Lipkin 2011:54). The Finnish prehistoric nålbound textile fragments are discussed in detail elsewhere in this paper (see below).

### Finnish ethnographic material and nålbinding folklore

Folklore has had a strong role in Finnish nålbinding research when the nålbound textile material from Finnish Late Iron Age burials has been interpreted. The prehistoric fragments have been defined as mittens merely based on the technique. For example, a decorated fragment was defined as a mitten by comparing it with decorated ethnographic mittens and neglecting the observation of the missing thumb (Vahter 1934). In addition, archaeological nålbinding finds were readily associated as white funeral mittens mentioned in folklore (Kaukonen 1960:56). However, at that time, the Finnish research knew only of nålbinding finds with bright, colourful yarns (Kaukonen 1960:66–69).

The prehistoric Kaukola fragments were interpreted as sock remains on the basis of the stripes, because there were striped socks in 20th-century ethnographic material (Vahter 1934). It should be noted that neither fragment has any remains of heels and nothing in the excavation data refers to socks.

The survey material from 1957, described by Kaukonen 1960, contains oral folklore, mittens, half-finished exemplars, and needles. The mitten samples of this survey were re-researched by the author and nålbinder Sanna-Mari Pihlajapiha in 2010 at the Ethnographic Archive of the National Board of Antiquities of Finland. It was discovered that the folklore and the actual textile samples provided contradictory information. For example, the optimal yarn for nålbinding was said to be s-spun and plied (Kaukonen 1960:56). However, amongst the ethnographic mittens, Z2s-, S2z-, and even S4z-plied yarns existed, and in general there was a greater variety of stitch types (Table 1).

### Notation systems

Nowadays, the most common way to describe the stitches in the nålbinding technique is Egon Hansen's notation (Hansen 1990). Hansen's notation consists

**Table 1.** Nålbinding mitten samples at the Ethnographic Archive of the National Board of Antiquities of Finland.

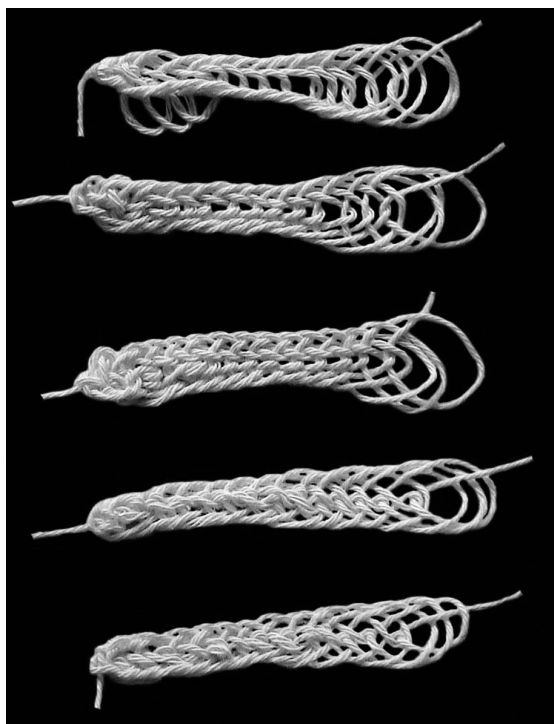
No.	Inventory number, site	The stitch family, notation	Twist of yarns
1.	KA 7758:4 Rautjärvi	The Finnish stitch, UU000/UUU000 F2	Z2s
2.	KA 7758:5 Rautjärvi	The Russian stitch, U00U/OUU00 F1 or F2	S2z
3.	KA 7758:7 Puumala	The Russian stitch, U00U/OUU00 F1 or F2	Z2s
4.	KA 7653:37 Vuoksenranta	The Finnish stitch, UU000/UUU000 F1	S2z
5.	KA 9170:5 Suojärvi	The Russian stitch, UU00UUU/000UU000 F2	S2z
6.	KA 9461:1 Rautjärvi	The Finnish stitch, UU000/UUU000 F2	S2z
7.	KA 9461:2 Rautjärvi	The Russian stitch, UU00U/OUU000 F2	S2z
8.	KA 9461:3 Rautjärvi	The Russian stitch, UOU/OU00 F2	S2z
9.	KA 9461:4 Rautjärvi	The Finnish Turning stitch, UU00(U/O)UU00 F2	S2z
10.	KA 9616:1 Rautjärvi	The Finnish stitch, UU000/UUU000 F2	S2z
11.	KA 9616:2 Rautjärvi	The Russian stitch, UU00UU/00UU000 F1 or F2	S2z
12.	KA 9616:3 Rautjärvi	The Finnish Turning stitch, UU00(O/U)U000 F1 or F2	S2z
13.	KA 9616:4 Heinjoki	The Finnish stitch, UU00/UU000 F1 or F2	Z2s
14.	KA 9616:5 Mikkelin mlk	The Russian stitch, F1	not determined
15.	KA 9616:6 Savitaipale	The Finnish stitch, U00/UU00 F1 or F2	not determined
16.	KA 9616:7 Parikkala	The Russian stitch UU00UU/00UU000 F2	Z2s
17.	KA 9616:8b Parikkala	The Finnish Turning stitch, "plaited edge" UU00(O/U)U00U FT	S2z
18.	KA 9616:9 Parikkala	The Russian stitch, UU00UU/00UU000 FT	S2z
19.	KA 9616:10 Parikkala	The Russian stitch, "plaited edge", UU00UU/00UU00U FT	S2z
20.	KA 9616:11 Polvijärvi	The Russian stitch U00UU/00UU00F2	S2z
21.	KA 9616:12 Nurmes	The Russian stitch U00UU/00UU00? F2	S4z
22.	KA 9616:13 Korpiselkä	The Russian stitch UU00UU/00UU000 F2	Z2s
23.	KA 9616:14 Ristijärvi	The Russian stitch U00UU/00UU0U, "plaited edge" F1 or F2	not determined
24.	KA 9616:15 Kiihtelysvaara	The Russian stitch, 2+2+2, UU00UU/00UU000 F1 or F2	S2z
25.	KA 9616:16 Paltamo	The Russian stitch, 1+2+2, U00UU/00UU00 F1	Z2s
26.	KA 9616:17 Pyhäjoki	The Finnish stitch, U000/UUU00 F1	S4z
27.	KA 9616:18 Jaakkima	The Finnish stitch, UU000/UUU000 F2	S2z

of the “U” and “O” letters and describes not only the course of the yarn in a single stitch, but also the joining direction and stitch count of the connection to the previous row (from front: F1, F2, from back: B1, B2, etc.). There is also an older notation system created by Odd Nordlund and a stitch typology classified by Margarethe Hald (Nordland 1960; Hald 1980:285–310).

Finnish folklore knows three stitch “families”; namely the Finnish stitch (UU00/UU000 F1 or 2), the Russian stitch (UU00UU/00UU000 F1 or

F2), and the Finnish Turning stitch (UUO Down U/O Up U000 F1 or F2)(Fig. 1). There are also other, local names for these stitches (Soisalon-Soininen 1956; 1957; Kaukonen 1960:61–63). In addition, there are variations in the loop count among the stitch families (Table 1). The prehistoric Finnish fragments (see Table 1) have mostly been made with the Finnish stitch, UU00/UU000 F1 or 2, but two fragments use its variation, the Kaukola Kekomäki stitch, UU00/UU000 Mid 1+F1.





**Figure 1.** From top to bottom: The Finnish stitch, the Russian stitch, the Russian stitch with a plaited edge, the Finnish Turning stitch, and the Finnish Turning stitch with a plaited edge.

Hansen's notation has been improved by adding the parameters "top", "mid", and "bottom" (Schmitt 2000:21–22), small "u" and "o" letters to describe the split yarn in some stitch types (Pihlajapiha, 2013a), and the parameter "T" to describe a certain type of joining through the stitch rows (Vajanto 2003:13, 15). The "plaited edge" structure (Vajanto 2003:14, 37) can be added to any stitch type when more density is desired. The "T" (through) joining can be found in both plaited-edge and "normally" stitched variants (Table 2). The Finnish turning stitch also has two variants from Joutseno. In these variants, the twisting of the loop is made with the fingers or in the middle of the stitching process (Pihlajapiha 2013b).

The double or multiple spirals make significant changes in the structure at the starting point and on the texture by creating skewed stitch rows. The author's suggestion is that in the striped textiles, the number of independent stitch rows should be calculated and marked, for example, with the letter "X".

## Finnish prehistoric nålbinding finds

The currently known fragments of nålbinding can be classified into three groups based on their visual parameters: monochromatic, embroidered, or striped (Table 1). The predominant twists of yarn are the z-spin or S2z-ply (about twists of yarn, see Gleba & Mannering 2012:11). This is typical of Finnish prehistoric textile material in general (Bender-Jørgensen 1992:93–100; Riikonen 2006:14).

### The monochromatic fragments

This group consists of fragments that have only one solid colour. Because the archaeological fragments are usually small, the monochromatic appearance may be only an illusion, and there might have been other colours in areas of the object that have not been preserved. For example, in the white Swedish Åsle mitten, dated to 1510–1640 AD, the wrist part is decorated with red and green yarns (Arbman & Strömberg 1934; Nockert & Possnert 2002:65–67). In addition, the textiles that seem to be undyed might contain faded dyes that cannot be detected with visual analysis.

There are monochromatic and possibly undyed fragments from Masku Humikkala grave 30 (Tomanterä 1982:161), Perniö Yliskylä grave 6 (Appelgren-Kivalo 1907), and Köyliö Köyliönsaari C, grave 28 (Cleve 1978:41–42; Tomanterä 1987:119, 120; Vajanto 2003:23, 27). The fragment from Piikkiö Huttalanmäki has been published with no mention of colours (Luoto & Fischer 1989:49; Riikonen 2006:15). The fragment from Halikko Rikala grave 38 is made of white wool (Mäntylä 2011:225–226), but the probably felted fragment from same site is solid reddish brown (Tomanterä 1987:120; Mäntylä 2011:233).

The tiny fragment from Kaarina Kirkkomäki grave 1 is blue (Tomanterä 1987:118–119; Riikonen 1990:77; 2003:240), but the colour might be a result of contamination from other blue textiles in this grave (Riikonen 1990:77; 2003:242–246). In addition, there are nålbound fragments from Kaarina Kirkkomäki graves 21, 23, 24, 27, and 40 with no mention of possible colours (Asplund & Riikonen 2007:21; Kirjavainen & Riikonen 2005:33; 2007:135; Riikonen 2011:211).

**Table 2.** Nålbinding fragments from Iron Age burials.

No.	Inv. number, site	Date, burial	Context	Yarns	Hansen's notation	Size
1.	Eura Luistari, Grave 56 NM 18000:1696 NM 18000:1700 NM 18000:1702	11 <sup>th</sup> century AD female	near hand bones, finger rings and a bronze knife sheath	yellowish: S2z red: S2z blue: 2z	the Finnish stitch UU00/UU000 F2 blue: split F2 or F1	3 x 2.5cm, 3.5 x 2cm, 9 x 5 cm
2.	Halikko Rikala NM 12690:475	11 <sup>th</sup> century AD	stray find	felted?	not determined	6 x 4 cm
3.	Halikko Rikala Grave 38 NM 12841:29	11 <sup>th</sup> century AD male	near a bronze finger ring	S2z	the Finnish stitch, F joining	2.5 x 2 cm
4.	Kaarina Kirkkomäki Grave 1 NM 12687	11 <sup>th</sup> century AD female	near a bronze knife sheath	S2z	the Finnish stitch, F joining	1 x 1 cm
5.	Kaarina Kirkkomäki Grave 31 NM 27196:H 31:101	11 <sup>th</sup> –12 <sup>th</sup> c. AD female	near finger bones and a bronze knife sheath	dark: S2z white: 2z or loose S2z	the Finnish Turning stitch or the Finnish stitch, F1 joining	4.5 x 4 cm 2 x 1 cm
6.– 10.	Kaarina Kirkkomäki Graves 21, 23, 24, 27, 40	11 <sup>th</sup> century AD female (grave 24: male)	middle part of the grave, near bronze items	not determined	not determined	not determined
11.	Kaukola Kekomäki Grave 1 NM 2489:40	13–14 <sup>th</sup> c. AD female	near a finger ring	all colours: 2z or loose Sz	the Kaukola Kekomäki stitch U00/UU00 Mid 1+F1	6.7 x 5.8 cm
12.	Kaukola Kekomäki Grave 1 NM 2489:49	13–14 <sup>th</sup> c. AD female	near an apron hem ornamented with bronze spirals	all colours: 2z or loose Sz	the Kaukola Kekomäki stitch U00/UU00 Mid 1+F1	6.7 x 5.8 cm
13.	Köyliö Köyliönsaari Grave 28 NM 8723:308	11 <sup>th</sup> century AD female	near a bronze bracelet	S2z	the Finnish stitch, F joining	2.5 x 1.5 cm
14.	Köyliö Köyliönsaari Grave 28 NM 8723:315	11 <sup>th</sup> century AD female	near a bronze knife sheath	S2z	the Finnish stitch, F joining	2 x 3 cm
15.	Masku Humikkala Grave 30 NM 8656:H30	11 <sup>th</sup> century AD female	middle part of grave, near hand bones	2z	The Finnish stitch UU00/UU000 F2	3.5 x 1.7 cm
16.	Mikkeli Tuukkala NM 9770:4 Grave 1/1933	13–14 <sup>th</sup> century AD male	unknown	Z2s decoration: loose s or untwisted	The Finnish stitch UU00/UU000 F2	18 x 5.5 cm
17.	Mikkeli Tuukkala NM 99 69:14	13 <sup>th</sup> century AD female	unknown	s or unplied, felted decoration: z	The Finnish stitch UU00/UU000 F2	10 x 10.5 cm
18.	Perniö Yliskylä Grave 6 NM 2919:95	12 <sup>th</sup> century AD female	stuck to a bronze finger ring	2z	The Finnish stitch UU00/UU000 F2	2.5 x 1.5 cm
19.	Piikkiö Huttalanmäki Grave G2	11 <sup>th</sup> century AD female	near a foot bone	not determined	not determined	not determined

### The embroidered fragments

From Mikkeli Tuukkala, there are two embroidered fragments that have been excavated by non-archaeologists (Tomanterä 1987; Lehtosalo-Hilander 1988:206–207). The fragment from grave 1/1933 has been made of possibly undyed white wool. The textile has been

decorated with blue or green yarns using chain stitch, herringbone styled stitch, and stem stitch (Vahter 1934:237; Kaukonen 1960:69). Some reddish embroidery is also present (Vajanto 2003:27–28, 32). The other embroidered fragment is a stray find and has been



**Figure 2.** Fragment Eura Luistari NM 18000:1702, the reverse side. The archaeological collections of the National Museum of Finland.

made of possibly undyed and probably slightly felted white sheep’s wool. The textile has herringbone and stem stitch decoration that has been made with blue and reddish yarns (Kaukonen 1960:66–67; Tomanterä 1987:117; Vajanto 2003:27, 32).

**The striped fragments**

There are three-coloured nålbinding fragments from Eura Luistari grave 56 (Lehtosalo-Hilander 1978:31–32; 1982:89–93, Plate 28; 2001:63; Lehtosalo-Hilander *et al.* 1982:20–21, 32, 41; Tomanterä 1978:54–57; 1987). Fragments with three repeating colourful stripes have been found in Kaukola Kekomäki grave 1 (Schwindt 1893:16–20, Plate 45). The stripes seem to be bluish, white/undyed, and reddish brown (Vajanto 2003:25, 27, 31), but because of fading and contamination from soil, it is impossible to determine the original shade of the colour.

From Kaarina Kirkkomäki grave 31, there are two-coloured fragments (Aaltio 2011:8) that have both dark and light coloured yarns. The replica mitten based on these fragments was made with the Finnish Turning stitch (Aaltio 2011), but the author’s interpretation is that the fragments might have been made with the Finnish stitch with F joining and with high loop count.

**Case study: Research and results of the nålbound Eura Luistari fragments**

To increase our knowledge of prehistoric nålbound textiles, some samples from the Eura Luistari fragment were subjected to closer research.

**Visual analysis of the Luistari fragments**

The nålbound fragments from the inhumation cemetery at Eura Luistari were found in the female grave 56 (Lehtosalo-Hilander 1978:31–32; 1982:89–93, Plate 28; 2001:63; Tomanterä 1978:54–58; 1987:117–118; Lehtosalo-Hilander *et al.* 1982:21, 41). The fragment NM 18 000:1702 was stuck to a bronze knife sheath, which had preserved the yarns in excellent condition (Fig. 2). This better side was interpreted to be the reverse side of the textile. The front side was more degraded and covered with bark. In addition, there are some smaller fragments (Vajanto 2003).

Fragment NM 18 000:1702 has red, yellowish, and blue yarns, while the other, smaller fragments have only remains of red and yellowish yarns (Table 3). The red and yellowish yarns are S2z-plyed, while the blue yarns are s-spun and used in pairs (Vajanto 2003:34). All the yarns have been spun with a moderate degree of twist.

The red and yellowish stitch rows have F2 joining and are skewed when compared to the blue stitch rows that are more horizontal (Vajanto 2003:41). These

**Table 3.** Visual analysis data of the Eura Luistari NM18000:1702 yarns.

Colour	Twist	Diameter	Spinning angle	Plying angle
Red	S2z	2 mm	30–40°	25–40°
Yellow	S2z	2 mm	45–55°	30–40°
Blue	2s	1 mm	30–50°	–

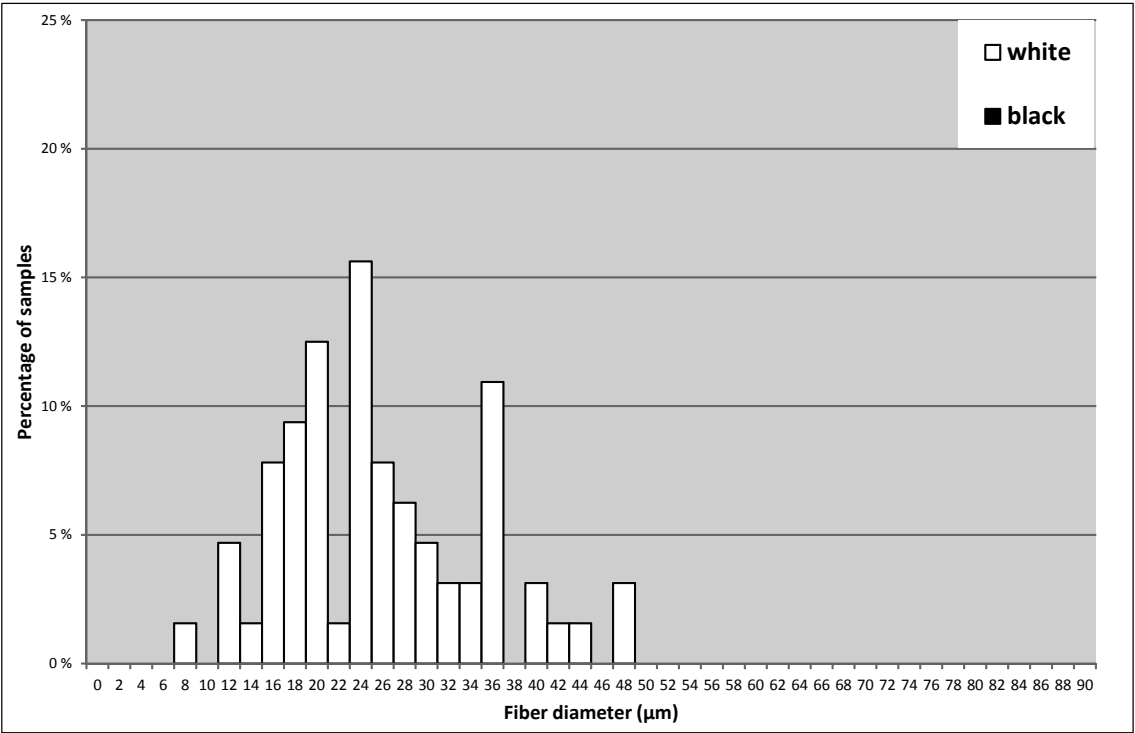


Figure 3. Fibre distribution of the fragment Eura Luistari NM 18000:1969, sample A.

blue rows probably have F1 joining or split F2 joining, that is, instead of stitching through the loop formed by the two parallel yarns, only one yarn was caught in the connection stitch.

Fibres of the Luistari fragments

Loose yarns from fragment NM 18000:1969 (sample A, yellowish yarn) and from fragment NM 18000:1702 (samples B and C, red yarn) were selected for a closer study to determine fibre materials, dyes, and wool types. One millimetre was cut from samples A, B, and C each and placed on a glass slide under a covering glass with distilled water as medium (Ryder 2000:2–8). Due to the poor condition of the fibres, the recommended 100 fibres could not be measured from sample A, but the results can be taken as a good approximation (Kirjavainen & Riikonen 2007:135). The diameters of the samples were measured with a Leica DMLS (DFC 420) transmitted light microscope without dyeing and by using the Leica LAS Core V 3.6 program. The fibre measurement data was loaded into the Excel program for empiric statistical fibre analysis.

Sample A was spun from white Hairy medium/Generalised medium, where the median was at 24.5 µm (n=65 fibres) (Fig. 3; Table 4). Sample B contained white and some black fibres. The wool type was Hairy with a median at 21.90 µm (n= 104 fibres) (Fig. 4; Table 4). Both samples contained mainly underwool that can be obtained by sorting the fleece or collecting the

Table 4. Fibre analysis data of Eura Luistari yellowish yarn (Sample A) and red yarn (Samples B and C).

	Sample A	Samples B & C
Number of samples (100%)	64	104
White fibres (%)	100	97
Pigmented fibres (%)	0	3
Medullated (%)	0	4
Median (µm)	24.5	21.90
Average	25.67	23.92
Standard deviation	9.12	11.27
Mode	24	22
Variance	83	127

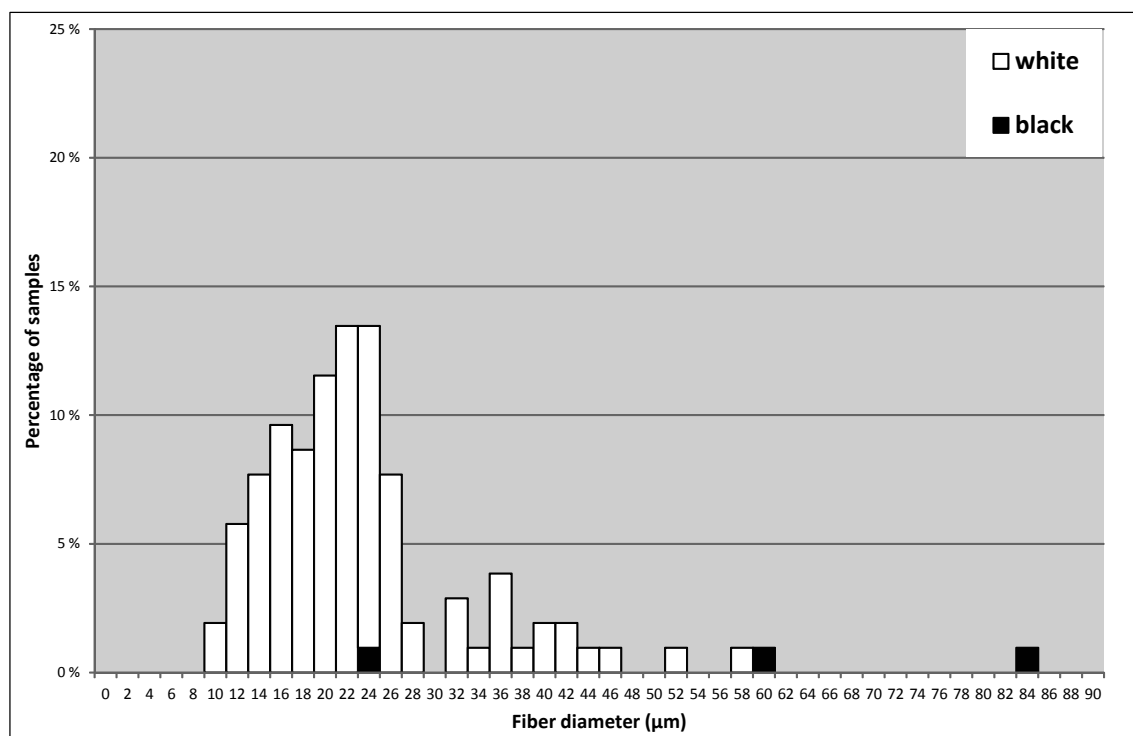


Figure 4. Fibre distribution of the fragment Eura Luistari NM 18000:1702, samples B and C.

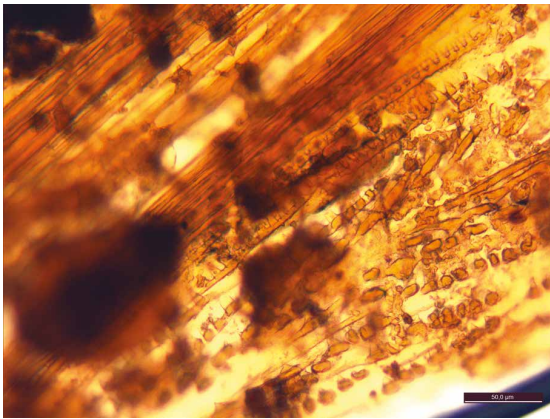
underwool during the natural shedding time. The blue yarn in fragment NM 18000:1702 was analysed visually without sampling. In this yarn, the fibres seemed to be finer than in the other yarns. In addition, these fibres were very shiny.

Sample C contained not only sheep wool, but also undetermined fur hairs with a pearl-string-like medulla and minor particles of probable bast fibres (Fig. 5). These were oriented similarly to the wool fibres. The diameters of the fur hairs were ca. 10–20 μm and the fibres were orange in colour, probably because of the bedstraw dye found in the HPLC analysis (see below). The hairs might have been spun into the yarn with wool on purpose, or there might have been some contamination before, during, or after the spinning process. In the North, the Sami people spun hare yarns as late as the 17th century to make soft caps and mittens (Itkonen 1979:222). Hare yarn has also been found in a Greenlandic textile as a decorative stripe in sheep's wool twill (Walton Rogers 2004:83; Østergård 2004:71). Alternatively, these fibres could originate from fur lining, a piece of fur, or a fur garment.

### Dyes of the Luistari fragments

The yellowish sample A was sent for HPLC-PDA analysis to the Cultural Heritage Agency of the Netherlands. The analysis found purpurin as main colourant, but also alizarin, indirubin, and indigotin were detected. No yellow dyestuffs were found (Van Bommel 2013). The yellow shade of colour in sample A was possibly a combination of blue and red dyestuffs. It is difficult to say whether this shade was dyed on purpose or whether it is the result of migrated dyestuffs. Even a very small amount of dye on a white wool yarn could cause a colourful effect.

The red samples B and C from the fragment were sent for HPLC-DAD dye analysis to IRPA/KIK, the Royal Institute for Cultural Heritage of Belgium. It was discovered that the samples contained mainly purpurin with only small amounts of alizarin and xanthopurpurin (Vanden Berghe 2012a:6, 11). The combination of the red compounds was typical of dyes derived from plants of the *Rubiaceae* family (Cardon 2007:122–127). Although alizarin was present in the samples, its ratio to purpurin was very low, which ex-



**Figure 5.** Animal hairs and probable bast fibres from the fragment Eura Luistari NM18000:1702, sample C. Scale bar 50 µm.

cluded the use of dyer's madder (*Rubia tinctorium*) (Vanden Berghe 2012a:11; Van Bommel 2013). Possible sources of red dye in samples A, B, and C are white bedstraw (*Galium mollugo* L.) and northern bedstraw (*Galium boreale* L.) (Proaño Gaibor 2011:1–4, 80–82; Van Bommel 2013), as well as lady's bedstraw (*Galium verum* L.) and dyer's woodruff (*Asperula tinctoria* L.) (Vanden Berghe 2012b:13, 17–18).

No direct local parallel for the bedstraw dye has been found among Finnish prehistoric textiles. Traces of alizarin have previously been detected from only one Late Iron Age Finnish sample. This textile is the band of a leg binding from the Kaarina Kirkkomäki inhumation cemetery, and it is dated to the 11th century AD (Kirjavainen & Riikonen 2005:40; 2007:137). Elsewhere in contemporary Europe, textiles were dyed red with cultivated dyer's madder (Cardon 2007:120).

The blue yarn was left out of the dye analysis, because there were remains of it only in one fragment. The blue dye is probably from woad (*Isatis tinctoria*), which was cultivated on a large scale in contemporary Central Europe (Cardon 2007:374–376) and is found in small quantities in fragment A. The indigo pigment is identical in both woad and the tropical indigo shrub (*Indigofera tinctoria*), but there has been speculation on when the true indigo was traded to Europe for the first time (Cardon 2007:335, 362–364). In the North, the Vikings' marine route to the east and back followed the coast of Finland and resulted in a great amount of eastern silver coins on the coasts of the Baltic Sea

(Lehtosalo-Hilander 1984:317–319). The true indigo dye could have been a trade article like the silver coins and other trade items.

### Luistari fragments and experimental archaeology

The first replica based on these fragments was inspired by the wishes to complete the so-called Eura costume with a pair of mittens. It was made with one spiral row interlacing the red and yellow yarns (Vajanto 2003). There were transition places from yellow to red and back, similarly to some ethnographic textiles (Kaukonen 1960:64). This seemed to indicate that the red stitch row of the fragment, which lies between the yellowish and the blue ones, would have been the beginning of the thumb. The stripes in this replica textile were more or less horizontal (Fig. 6).

Another replica was made using the double spiral technique that has lately become popular among modern nålbinders. This technique is unknown or at least poorly recognised in the ethnographic material. In this method, there are independent and parallel stitch rows for each colour of the striped area. There are no transition places from one colour to another. The triple spiral technique might be present in the Kaukola Kekomäki fragments.



**Figure 6.** The replica presented in the author's Master's thesis (Vajanto 2003).





**Figure 7.** The new replica with the double spiral technique in the striped area.

The replica with double spiral technique in the striped area is highly comparable with the three-coloured fragment NM 18000:1702 from Eura Luistari. The yellow and red rows (2X UUOO/UUOOO F2) are similarly skewed and the blue rows (as 1X UUOO/UUOOO F1) are similarly horizontal (Fig. 7). Unfortunately the double spiral technique seems to exclude the presence of a thumb in the Eura Luistari NM 18000:1702 fragment. In the new replica, the red area that is between the yellow and blue rows is just the end of the red spiral row. Nothing in the fragment proves the existence of a thumb. It could, of course, have been situated somewhere in the unpreserved area.

### Reconsidering the interpretations

The nålbinding technique itself should not be used as a parameter to define the shape and use of a prehistoric textile. For instance, we don't define all twill fragments

as dress remains either. It is true that most of the prehistoric Finnish nålbinding finds are from the middle part of the grave, often near the hand bones (Vahter 1934:237; Riikonen 1990:77, 105). But this is also the location of bronze finger rings and knife sheaths that play a major role in the preservation of organic textile materials. Consequently, the find place of the nålbinding fragments indicates only the place of *optimal preservation* of organic material as a result of bronze oxides and bone calcium and provides little information about the function of the textiles.

The double spiral technique has been hitherto found only in the striped prehistoric fragments and is unknown in the younger material. This implies changes in the stitching tradition and might indicate that the purpose of the prehistoric nålbound textiles was different than those of the younger periods. Consequently, it can be questioned whether the Finnish ethnographic data is too recent to be used as an ethnographic parallel to the prehistoric textiles.

The folklore and survey material described by Vahter and Kaukonen provide with all likelihood some facts about nålbinding in the 19–20th centuries AD, but it is difficult to estimate the reliability of folklore and to know what facts are useful for textile-archaeological research. At least the twists of yarns that were announced to be optimal for nålbinding (Kaukonen 1960:56) differ from the yarns of ethnographic mitten material obtained in the very same survey (Table 1).

Due to the obvious colours, the Eura Luistari textiles and several other prehistoric nålbound textiles might have no connection with the white funeral mittens described in Finnish folklore (Kaukonen 1960:56). The white mittens might be a relatively new phenomenon or a cultural loan. At least in 19th–20th-century Estonia, there is folklore data on white funeral mittens (Peets 1987:110). The fragments from Kaarina Kirkkomäki graves 1 and 23 suggest that the nålbound textiles were not simple winter mittens at all. On the basis of macrofossil finds, these burials were carried out in the summer (Riikonen 2003:234, 240–241; *pers. comm.* 2012). The rare bedstraw dye found in the Eura Luistari fragment might imply a textile with a very special meaning.

The Eura Luistari fragments, which are made with the double spiral technique, have no remains of a thumb. Remains of thumbs or heels are not found in other Finnish fragments either. This can be just a coincidence, but based on the material we have now, no prehistoric fragments can be clearly defined as mittens or socks. Perhaps these fragments are the remains of some kind of pouches with a still unknown function.

## Conclusions

The nålbinding technique has been applied to several kinds of textiles. The Finnish folklore data related to nålbinding and the nålbound textiles in the Finnish ethnographic collections have influenced the interpretation of Finnish archaeological finds as mittens or socks. It can be questioned whether this data is too recent to use as an ethnographic parallel to the prehistoric 11th–14th-century-AD material. Half of the Finnish prehistoric nålbound textiles are colourful, not like the white funeral mittens that were described in the survey material obtained in the 20th century AD. The absence of the double spiral technique from the younger material might indicate deeper changes in the nålbinding tradition.

In the Finnish prehistoric finds, the placement near the hand bones does not confirm the nålbinding finds as remains of mittens. This area often has most of the bronze remains, which preserve the organic material and textiles. The placement indicates only the optimal place of preservation for organic material.

The double spiral technique produces a textile structure that is identical to the nålbound archaeological fragment of Eura Luistari NM 18000:1702, where the differently coloured stitch rows are skewed. This excludes the presence of a thumb from this Eura Luistari fragment. There is no evidence for thumbs or heels in other prehistoric fragments either. Consequently, the prehistoric Finnish nålbound finds could have been some kind of pouches with an unknown purpose.

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# Finnish shipwreck textiles from the 13th–18th centuries AD

Krista Vajanto

## ABSTRACT

*This article discusses textile fragments that have been found in shipwrecks off the coast of Finland. The finds have been dated to the 13th–18th centuries AD. All samples were researched with visual analysis, but XRF, FTIR, SEM and HPLC was applied to part of the finds. The fragments of a woollen 2/1 twill from the Lapuri wreck were here interpreted as the remains of a red ochre treated sail cloth. The finds from the Egelskär wreck were interpreted as remains of a sheepskin. Other discussed finds are a woollen tabby weave from the Mulan wreck, fragments of a red woollen broadcloth from the Vrouw Maria, and a woollen sock and a silken rococo petticoat with woollen batting from the Sankt Michel. The aim is to shed light on textiles that form an understudied group of Finnish archaeological textile finds.*

*Keywords: shipwreck textiles, visual analysis, wool, mohair, camlet, sail fabric, petticoat*

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## 1. Introduction

In Finnish archaeology the shipwreck textiles have rarely been researched. This article sheds light on these rare finds: a sheepskin; two fragments of 2/1 twill; a tabby woven fragment; a petticoat; a sock, and a napped broadcloth. All the finds were studied with visual analysis and part of them with additional analyses using FTIR, SEM and XRF to gain new insights on these finds. The results will here be discussed within the textile archaeological framework to understand the finds as fragments of their own age's culture history.

The Baltic Sea as a connector of distant shores through maritime routes has been important from prehistory to the present. The archipelago offered the sailors natural harbours for resting, preparing food and waiting for better weather. The coastal waters of Finland are relatively shallow and have tens of thousands of islands, skerries and rocks. Since the shipworm *Teredo navalis* does not live in the brackish water of the Baltic Sea, the ships that are sunk deep enough to avoid winter ice formations are preserved in relatively good condition (Leino et al. 2011, 137; Steffen and Montonen 2012, 222–229). However, of the numerous shipwrecks found in Finland only a few have been excavated archaeologically and only few of the excavated wrecks have contained textile fragments, which makes their study even more precious for the field of textile archaeology.

## 2. Shipwrecks with textile finds

The studied archaeological textiles have been dated to the 13th–18th centuries AD. The wrecks have been named after the island nearest the site, except the Sankt Michel and the Vrouw Maria (Map 9). These wrecks were identified according to the Danish Toll Sound register, the archive sources about the salvaged goods, the measurements made at the wrecks and the type of the ships' cargos (Ahlström 1978 and 2005; Gelderblom 2003; Matikka 2012, 90–101; Alvik 2012, 108–131).



1. Vrouw Maria
2. Egelskär
3. Sankt Michel
4. Mulan
5. Lapuri

Map 9. Placenames mentioned in the article of Vajanto. Illustration: K. Vajanto.

## 2.1 The Lapuri wreck

The Lapuri wreck is situated in a natural harbour at the eastern corner of the Gulf of Finland in a place that has excellent connections to both east and west. It is known that the Vikings' maritime route to Constantinople followed the Gulf of Finland (Lehtosalo-Hilander 1984, 319–322). Because she is clinker built, as were the Viking ships, she was interpreted as a Viking ship in the first research (Alopeus 1985 and 1995).

The *Lapuri* wreck is 13.8 x 4.4 m in size and made of oak. The wooden parts of the ship have been dated with dendrochronology and the C-14-method to the last quarter of the 13th century AD. Some parts and materials, like animal hair caulking, might be older or contaminated somehow. A whetstone and early medieval ceramics were found in underwater archaeological excavations (Mökkönen 2006, 40–44; Wessman 2007, 141–142).

Two textile fragments SMM 2592:8 (c. 10 x 25 cm) and SMM 1393:27 (c. 4 x 8 cm) were found placed in between the wooden planks. Nail holes were present in both of the fragments. This might be a secondary deposit of the textiles. The fragments were woven in 2/1 twill, using very tightly z-spun yarns (warp?) in one system and Sz-plyed (weft?) in another. Due to the strong similarity in the yarns and the thread counts, the fragments are probably from a single textile. The fragment SMM 2592:8 has been repaired with darning stitches during its time of use. The course of the reddish darning yarn does not follow the shed, but rather only imitates a twill structure (Vajanto 2013). The fragments are here examined to explain the clearly visible, distinct colours of the yarns and the original purpose of the textile.

## 2.2 The Egelskär wreck

The badly destroyed *Egelskär* wreck is situated in the Archipelago Sea. Her departure or target harbours are unknown. However, she was not sailing in unpopulated territories, because there is evidence of Medieval (1150/1300–1550 AD) and even earlier inhabitation on the largest islands of the Archipelago sea (Edgren 1977; Tuovinen 1990 and 2002). Perhaps she was lost from the fairway, which is described in the so-called *Danish Itinerary*, written in the 13th century (Edgren 1995). That route follows the coast of Finland from Sweden to Estonia (Gallén 1993; Dahlström 1966) and presents the safe harbours and distances between them.

The *Egelskär* wreck is clinker built and lies in shallow water. The surviving part of the keel is c. 8 m. She had cargo of stoneware ceramics that has been dated to the early 14th century AD. In addition, she was carrying a bronze church bell, whetstones and a barrel full of iron bars (Wessman 2007, 142–144). The iron bars were covered with fibre material, which was identified to be sheep wool (Wessman 2007; Vajanto 2013). The fibres were examined in order to find any dyestuffs that could explain the sample's distinct orange shade of colour.

## 2.3. The Mulan wreck

The *Mulan* wreck (12 x 4.7 m) was found in the Gulf of Finland, near the Hanko peninsula, that was a natural harbour well known in medieval times (Niitemaa 1964, 22). She is made mostly of pine, but the exact type is unknown. She was probably wrecked shortly after the year 1611 AD according to a Dutch coin find and a dendrochronological analysis. This ship had various cargo items: bricks, two church bells with Cyrillic inscriptions, wooden vessels, tiles, guns and gunpowder. The cargo might have been the spoils of war, originally from Russia and the ship was possibly headed to Sweden (Vaheri 1996, 48–49).

The researched textile SMM 1494:21 was found near the rudder. The textile is c. 89 cm<sup>2</sup> in size, but in several pieces. The fragments may have originally formed a square textile, because there is a corner present. The visible shade of colour of the fragments is reddish. The colour and the purpose of the textile are here studied more closely.

## 2.4 The wreck of the *Sankt Michel*

The best sailing season in the Finnish waters is and has been during the summer time in the period of the so-called white nights. During the winter and early spring, sailing is not possible because of the sea ice covering. The desire for profit and gain made the captains try to sail as late as possible in autumn despite storms and shortening days with increasing darkness. This probably explains why the *Sankt Michel* sank to the Sea of the Archipelago in late October in 1747 on her way to Saint Petersburg (Rigsarkivet, Copenhagen, Denmark. The Sound Toll Registers. Østend customs accounts: 15 October 1747, RaDk).

The *Sankt Michel* (25 x 7 m) had a valuable cargo consisting of cotton fabrics, sewing thread, Meissen porcelain, a horse chariot, and small luxury items such as pocket watches and snuffboxes (Alvik 2012, 108–132; RaDk, The Sound Toll register 15 Oct. 1747). The largest Finnish shipwreck textile, a rococo petticoat (SMM 62001:127), is from the *Sankt Michel*. The bones of a young woman were excavated from the wreck, but it is unknown, whether this was her petticoat. The petticoat is c. 300 centimetres long and c. 100 centimetres wide. This fabric consists of two layers of silk with batting made of wool. The silk was decorated with floral patterned quilting using silk thread and silver pearls (Pylkkänen 1982, 67; Ehanti 2012, 63). For this paper, the fibre material of the petticoat's batting was taken for closer examination.

In addition, there are textiles from a luggage chest including a ball of wool yarn, the remains of a possible hat, several pairs of wool socks and a fragment of a silk sock made in Nîmes, France (Pylkkänen 1982, 334; Vajanto 2012a, 135–136). The wool sock SMM 62001:120 is perfectly preserved. It is c. 70 centimetres long from heel to knee and c. 26 centimetres from heel to toe. A sample from the sock was taken for this study in order to determine the condition of the fibres and any new information that could be obtained from a find that was excavated decades ago.

## 2.5 The wreck of the *Vrouw Maria*

Before the invention of modern navigational equipment, navigation was done visually by following known landmarks. The demanding environment and errors in navigation explain why the *Vrouw Maria* (26 x 7 m) sank to the Archipelago Sea in a storm in late September in 1771 on her way to Saint Petersburg (Ahlström 2005, 98). She was loaded in the port of Amsterdam with over twelve thousand kilograms of precious dyestuffs and mordants, cotton and wool fabrics, coffee beans, porcelain and small luxury items, and famous paintings for the empress Catherine the Great of Russia (Gelderblom 2003; Rigsarkivet, Copenhagen, Denmark. The Sound Toll Registers. Østend customs accounts: 23 September 1771; Vajanto 2012b).

Part of the textiles and dyestuffs were salvaged right after the shipwreck (Riksarkivet, Stockholm. *Inkomna handlingar, Kabinettet, RA. Huvudserie. E 1 A:11* (vol 11), but part of the material is still *in situ* in the cargo hold in the original wooden package boxes (Vajanto and Alvik 2011). Two textile samples from the *Vrouw Maria* were studied for this paper. The first one is 1 x 1 cm in size and excavated from the wreck in 2011 (Vajanto 2012a, 134). The latter sample is 1.5 x 2 cm in size, excavated in 2012. These are both only tiny samples of a large, but fragmented textile material that is still *in situ* in the wreck.

## 3. Methods

In Finland, invasive research permission is granted by the National Board of Antiquities only if the research methods are well known and trusted. The aim is to preserve the finds as intact as possible for the future generations. Therefore, the traditional textile archaeological methods i.e., visual analysis and micro-destructive methods with a small sample size, were selected for this study.

### 3.1 Microscopic analyses

The study of the archaeological textile finds was begun with visual analysis using a stereoscopic microscope and digital photographs. The size of the item, structures, the twist direction and the diameter of the yarns, the thread count per centimetre were determined as well as the spinning and plying angles.

Fibre identification was made with a transmitted light microscope by observing morphological features and by measuring the diameter of the fibres. In order to ensure that the observations made with the transmitted light microscope were correct, the fibres were pictures at Aalto University School of Science, Department of Applied Physics with a scanning electron microscope (SEM). The type of the device was JEOL JSM-7500F, the acceleration voltage was 2 kV, and the working distance c. 15 millimetres. The secondary electrons were collected with a detector of the Everhart-Thornley type, situated at the side wall of the research chamber. The samples were placed on aluminium planchets with double-sided carbon tape and coated with gold.

### 3.2 Wool type analysis (fibre analysis)

Wool type analysis groups different types of wools (Nahlik, 1963; Ryder 1974). It is known from archaeological record, that white and homogenous wool existed commonly in the Mediterranean area already 2000 years ago, but they did not arrive to northern Europe until hundreds of years later (Ryder 1974, 1978, 1983; Rast-Eicher 2008; Bender-Jørgensen and Walton 1986). In southern Europe, a Merino type of soft and white wool existed already in the 13th century (Lipson 1953, 37; Ryder 1987). In Finland, the double-coated wool has been found from the late Iron Age and early medieval samples (Kirjavainen 2005a, 2005b; Vajanto 2013). At the beginning of the 20th century there were serious attempts to evolve the Finnsheep's wool from primitive double-coated to soft and homogenous (Vohlonen 1919 and 1927).

The wool type analysis has been seen as a useful tool to determine the provenance of wool (Maik 1990, 122). This method has been criticised for fitting poorly to sorted wool that is often present in the yarns made of the primitive kind of wool (Christiansen 2004, 11–18; Rast-Eicher 2008, 153–155). Nevertheless, fibre analysis is a simple, but practical tool for grouping different fibre distributions of the yarns. The wool classes are Hairy, Hairy Medium, Medium, Generalised medium, Medium, Semi fine, Fine/Generalized medium and Fine (Walton 2004, 83).

In the fibre analysis, the diameters of the fibres are measured and the proportion of medullated fibres is counted from the population of at least of 100 fibres (Ryder 2000: 4). If possible, the warp and weft yarns should be analysed separately. It has been suggested that even 50 fibres would be sufficient (Kirjavainen 2005a, 135; Kirjavainen and Riikonen 2007, 135). This protocol with a smaller count could possibly fit to highly degraded material with a few measurable fibres. In this study, the fragment from Mulan contained quite degraded and partly mineralised fibres, and it was not possible to find a group of 100 fully preserved fibres from the sampled yarn. In this particular case, the warp and the weft were measured as a single population.

### 3.3 FTIR, XRF and HPLC analyses

X-ray fluorescence (XRF) and Fourier transform infrared (FTIR) analyses have been only rarely applied to Finnish archaeological textile research, and these methods were used in this study as an experimental approach. These analyses were done at the Metropolia University of the Applied Sciences of Finland, where these methods have been applied constantly in textile conservation. In the XRF analysis the elements of the samples were measured with a small portable device, the Innov-x (alpha series) using the standard modes to gather additional data to explain the visible shade of colour observed in the fibres from the *Egelskär* and *Lapuri* wrecks. The FTIR analysis was done using Nicolet spectrum 100 to identify chemical compounds of the heavily degraded fibres found in the textile sample from the *Vrouw Maria*.



Table 1. Main elements of the yarns of the *Lapuri* SMM 2592:8 and SMM 1393:27 samples.

Find	Yarn	Fe (ppm)	S (ppm)	Ca (ppm)
Lapuri, SMM 2592:8	warp	7290.51	259041.38	4739.42
Lapuri, SMM 1393:27	weft	20039.13	579162.19	9986.45
Lapuri, SMM 2592:8	darnings	-	840559.75	-

Samples sized 2–5 millimetres were taken from textile finds from the *Lapuri*, *Egelskär* and *Mulan* wrecks and sent for dye analysis to the Royal Institute for Cultural Heritage KIK/IRPA, Belgium. The analyses were carried out by researcher Ina Vanden Berghe with High Performance Liquid Chromatography (HPLC-DAD) following the normal extraction protocol for this method. In a HPLC analysis a negative result does not necessarily mean an undyed textile, but that the sample size has been too small or the material too mineralised. Additionally, a positive result can indicate either a true dye or contamination.

## 4. Results

### 4.1 Twill from the Lapuri wreck

The warp and weft yarns contain a primitive type of wool, which has previously been defined as Hairy medium/Generalised medium type (Vajanto 2013). This kind of wool contains fibres from both the soft underwool and the coarse outer coat hairs (Ryder 2000). The darning yarn has been spun from a naturally pigmented, brown Medium type of wool (Vajanto 2013).

The diameter of the z-twisted warp (SMM 1393:27) is one millimetre and the spinning angle c. 45–55°. The weft (SMM 2592:8) is also 1 millimetre in diameter, but spun with an angle of c. 45°, and plied with an angle of c. 45–65°. There are 10 ply twists per centimetre. The darning yarn had a spinning angle of c. 20°. There seemed to be two parallel darning yarns as a pair, or the darning yarn had been plied very loosely.

The z-spun yarn from warp (SMM 1393:27) and the tightly Sz-plied weft (SMM 2592:8) are dark, while the thick z-spun darning yarn (SMM 2592:8) is reddish. The HPLC-DAD analysis revealed ellagic acid, i.e., tannin from all the yarns (Vanden Berghe 2012, 12). The XRF found high proportions of iron (Fe) from the warp and the weft, when measured with the so-called soil mode. This mode sees not only the metal elements, but also some of the lighter elements. The darning yarn contained no iron at all, but sulphur (S) as main element. (Table 1)

### 4.2 Fleece from the Egelskär wreck

The fibre material of the SMM 342006:16 fragment is sheep wool (Vajanto 2013). The fibres are in good condition and the identification was based on the visual analysis of the scale pattern. The wool has previously been determined as Hairy type, with mostly white fibres (Vajanto 2013). There are no textile structures visible, that suggest the find as sheepskin.

In general, the fibres are deep orange in colour (Fig. 1). In the HPCL analysis, no organic dye compounds were found (Vanden Berghe 2012, 12). The XRF measurement (alloy mode) revealed that the sample contained iron as the main element (Fe 99.49%) and small quantities of tin (Si 0.51%).

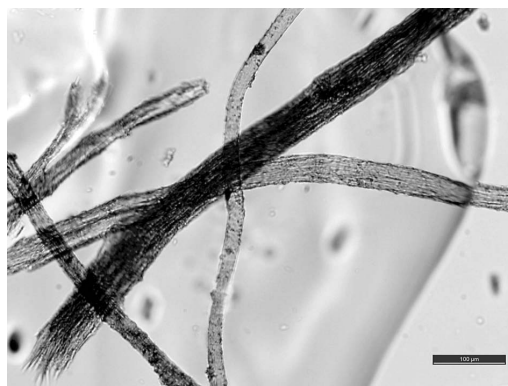


Fig. 1. Orange fibres from the fragment SMM 342006:16 from the *Egelskär* wreck. Photo: K. Vajanto.



Table 2. Statistical data of the wool analyses.

Find	Count of fibres	Median (µm)	Average (µm)	Standard deviation	Mode (µm)	Variance	Medullated (100 %)	Pigmented (100 %)	Wool Type
Mulan SMM 1494:21	103	21.00	24.29	10.51	18	111	12	2	Generalized medium
Sankt Michel SMM 62001:127	127	42.90	45.92	28.41	12	807	25	52	Hairy
Sankt Michel SMM 62001:120	110	24.00	24.54	3.92	24	15	0	0	Fine

Most likely, the orange colouring is rust, i.e., iron oxide, and contamination from the archaeological context.

#### 4.3. Tabby from the Mulan wreck

The fragment SMM 1494:21 has been woven in plain weave using s-spun yarn one and z-spun in other yarn system. The thread count is 12/12 per centimetre. The diameter of the yarns is 0.7–1 millimetres and the spinning angle 45°. The disorder of the fibres on the fabric's surface might refer to after-weave treating, like fulling or use marks of wearing.

The material of this fragment consisted mostly of white sheep wool (Tables 2 and 3). The average fibre diameter was found to be 24 µm, the range from 10 to 55 µm and the proportion of the medullated fibres was 12%. In HPLC analysis no organic dyes were found (Vanden Berghe 2012, 12), that might refer to an originally white textile.

#### 4.4 Textiles from the Sankt Michel

The silk fabric of the petticoat SMM 62001:127 is badly deteriorated and the dark woollen batting clearly visible. The quilting with a floral pattern consists only of needle stitch rows in the wool batting and the silken sewing thread has mostly vanished. The analysed silk fibres had a pinkish orange hue. The sample from the batting contained naturally pigmented (black and brown) fibres with only a few white fibres. The original colour of the fibres is difficult to determine, because some of the fibres had bluish and brownish shades and might have been dyed. In general, the sample contained both very thin and very thick sheep wool fibres (Fig. 2). The thickest fibres were medullated and even 120 µm in diameter; the thinnest was only 8 µm in diameter (Tables 2 and 4).

The material of the sock SMM 62001:120 is sheep wool. The diameter of the Sz-plyed yarn is 0.5 centimetres and spinning angle 20–30°. The sock has been knitted with the stockinette stitch c. 11 loops and 9 rows per centimetre. Carefully knitted decreases at the ankle area are typical to the socks from that period (Pylkkänen 1982, 333–337). The average fibre diameter in the sock was 24 µm and the diameter distribution from 16 to 34 µm. All fibres were unpigmented and no medullated fibres were present (Tables 2 and 5).

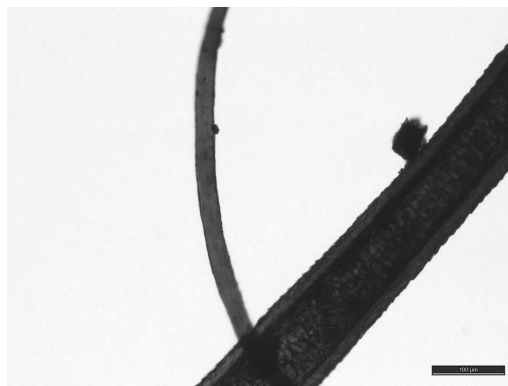


Fig. 2. Dark sheep wool from the batting of the petticoat SMM 62001:127 from the *Sankt Michel*. Photo: K. Vajanto.

Table 3. Wool analysis of the sample SMM 1494:21 from the *Mulan* wreck.

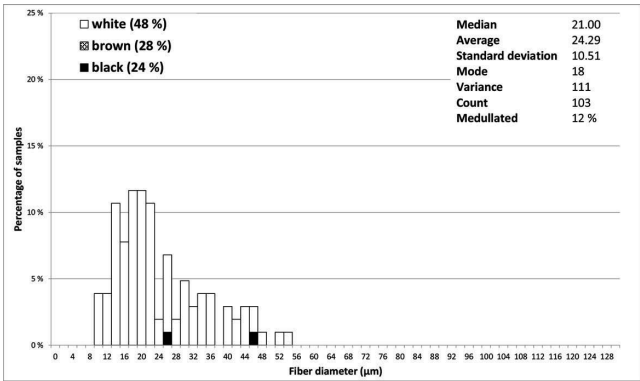


Table 4. Wool analysis of the batting of the petticoat SMM 62001:127 from the *Sankt Michel*.

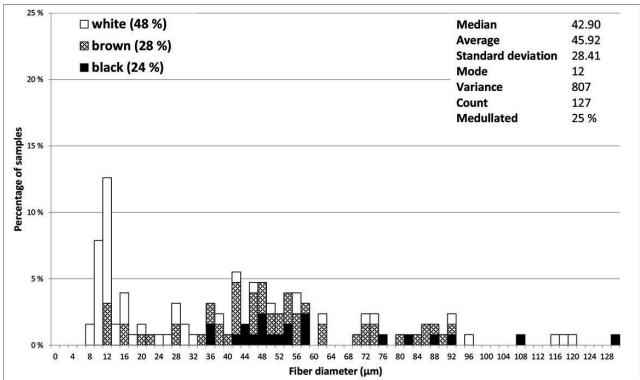
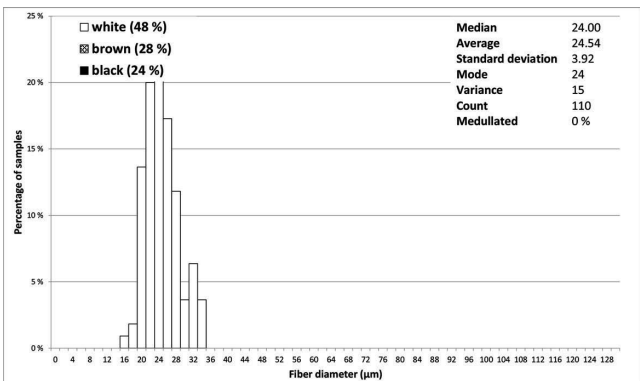


Table 5. Wool analysis of sock SMM 62001:120 from the *Sankt Michel*.



#### 4.5 Fragments from the *Vrouw Maria*

The fragments from the *Vrouw Maria* are warp-faced tabby weave. The warp is z-spun and has a spin angle of 45°, while the weft is very loosely s-spun. The thread count in the warp is 14 yarns per centimetre and in the weft 6 yarns per centimetre. The yarn diameter is consequently 0.5–1 and 1–2 millimetres. The fibres are in parallel position that refers to combed fibre material (Forbes 1987, 21) and a worsted yarn (Heaton 1965, 262–263).

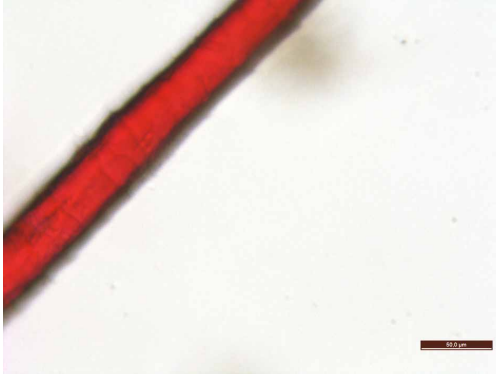


Fig. 3. Red and lustrous wool fibre from the *Vrouw Maria* fragment. Photo: K. Vajanto.

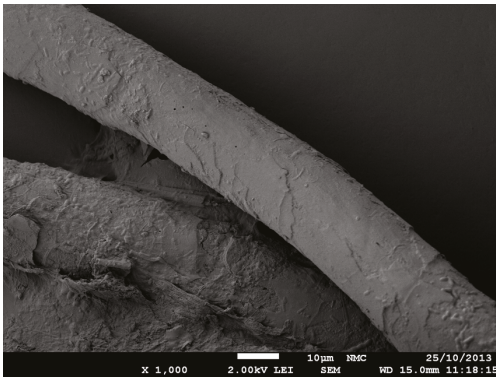


Fig. 4. SEM image of the mohair fibres from the *Vrouw Maria* fragment. Photo: A. Nykänen.



Fig. 5. Cotton fibre from the *Vrouw Maria* fragment. Photo: K. Vajanto.

The sample from the warp yarns contained deeply red, shiny fibres that had barely visible scales with long scale distance and a diameter of 18–20 µm (Fig. 3). In addition, there were thin, light pink fibres (8 µm) of possible white sheep wool. The “polished” feature of the deeply red fibres with shallow scales is typical to the mohair wool of the Angora goat (Appleyard 1978, 2). This observation was ensured with SEM images, in which the surface morphology of the fibre was found to be indeed more close to mohair than sheep wool (Fig. 4).

Most of the weft consisted of highly degraded fibres that had a pink-lilac shade of colour. The diameter of these fibres was 25–30 µm and there were no scales, but faint vertical lines (Fig. 5). The identification was not possible to do with the transmitted light microscope, because the degrading of fibres in the seawater changes the morphological features (Chen and Jakes 2001). In addition, the weft contained a few animal fibres that were c. 5–10 µm in diameter. These were possibly sheep wool, because there was not such a shine as was present in the thicker fibres of the warp yarn. A FTIR analysis indicated that both protein and celluloid material are present in the weft yarn (Fig. 6). The cellulose peak is similar in other plant fibres too, and FTIR is not adequate for the identification of the plant species. With the scanning electron microscope (SEM) an end of a flat and twisted fibre was found and the fibre was identified as cotton (Fig. 7).

The surface of the textile fragment was soft. The suspected mohair fibres of the warp covered the surface all over forming a nap. The nap is not cut, but possibly fulled (Fig. 8). Additional findings from the sample were silk fibres that formed a textile-like structure (Fig. 9). A plant fibre might be nettle (Fig. 10), because of a bulb formation (Karttila 2012, 24). It is known, that nettle fabrics were a part of the *Vrouw Maria*’s cargo (Riksarkivet, Stockholm. *Inkomna handlingar, Kabinettet, RA. Huvudserie. E 1 A:11* (vol 11). These fibres are possibly not connected to the red broadcloth fabric at all and perhaps the excavations in the future will explain these random findings.

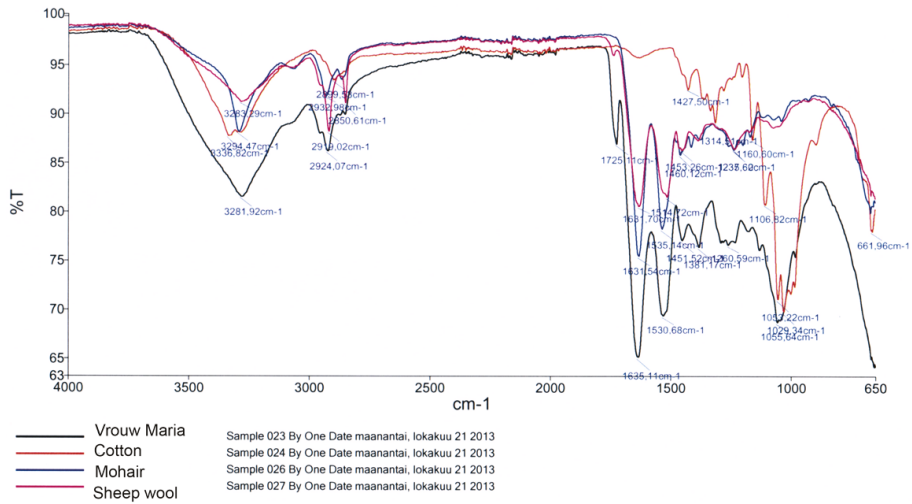


Fig. 6. FTIR spectrum from the weft yarn of the *Vrouw Maria* fragment with cotton, sheep wool and mohair references.



Fig. 7. SEM picture of the cotton fibre from the *Vrouw Maria* fragment. Photo: A. Nykänen.

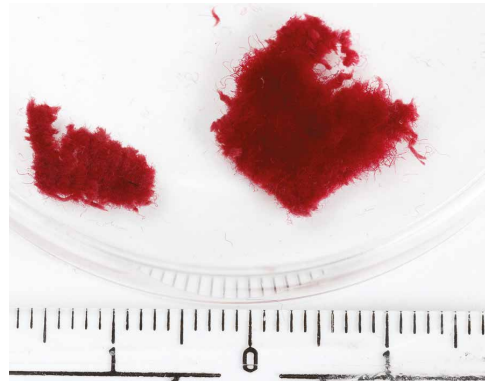


Fig. 8. The *Vrouw Maria* fragment. Courtesy of Riikka Alvik, National Board of Antiquities, Finland.

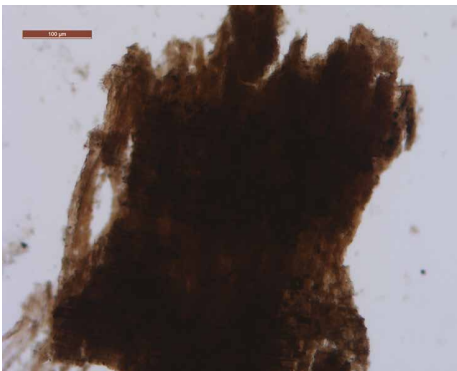


Fig. 9. Possible silk textile fragment from the *Vrouw Maria*. Photo: K. Vajanto.

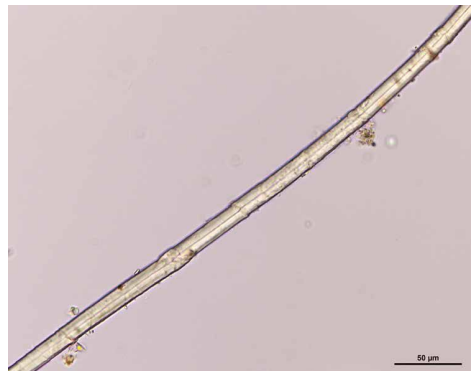


Fig. 10. Possible nettle fibre from the *Vrouw Maria*. Photo: K. Vajanto.

## 5. Discussion

### 5.1 A woollen sail from the Lapuri wreck?

It is known that iron (Fe), sulphur (S) and tannin accumulate naturally to underwater material (Fors 2008). Thus, the iron and sulphur found in the XRF measurements as well as the tannin found in the HPLC analysis might be contamination from the marine environment. To make the interpretation more complicated, the accumulation seems to be irregular; the finds from the *Egelskär* and the *Mulan* wrecks contained no tannins at all. In the case of the *Lapuri* fragments, the HPLC-detected tannin might be from the wreck itself, or it could be a dye or natural tannin mordant, that works well for wool (Vajanto 2010).

Usually the plied yarn of a textile is in the warp, but in the *Lapuri* fragments the unplied yarns formed a more regular order of the yarns. This feature is more natural to warp than weft, at least if there had been a reed directing the warp yarns. The use of plied yarn in the weft is understandable, if there has been a very large fabric in process. With the thicker weft yarns, it is possible to increase the length of fabric faster than when using thin yarns. The tight spin and ply and the long outer coat fibres add the breaking resistance of the yarn (Vajanto 2013, Vajanto in this publication).

With visual observation, the warp and weft yarns differed remarkably from the darning yarn made of reddish wool. The XRF measurements conformed to this, which suggest that the iron is not an accumulation product. The difference could be explained with a purposeful adding of iron to the newly woven fabric. The darning stitches were possibly done during a different event.

Experimental archaeology has proven that 2/1 woven sail works well in square-rigged boats (Andersen and Nordgård 2009). It is known from historical sources that woollen sails were woven in Scandinavia with 2/1 twill (Cooke et al. 2002). There is folklore knowledge wisdom about woollen sails that were *smörred*, which means that they were treated with a mixture of animal grease and red ochre (Cooke et. al. 2002, 205). Perhaps the *Lapuri* textile fragments once belonged to a *smörred* woollen sail, a fabric with a high tenacity. The original colour of the textile might have been reddish due to red ochre pigment. Brown wool was perhaps selected to the darning yarn on purpose just to fit to the colour of the reddish *smörred* fabric.

### 5.2 Sheep wool products

The examined shipwreck textiles were made of several kinds of sheep's wools. The wools from the *Lapuri* and the *Egelskär* wrecks were of double coated sheep (Vajanto 2013) and this conforms to what is known about the late Iron Age and early medieval wools found in Finland (Kirjavainen 2005a, 2005b; Ryder 1978).

The fragment from the *Mulan* wreck was possibly undyed and woven from naturally white Generalized medium wool. The fibre distribution is close to the wool from the English sheep found in Medieval Gdansk, Poland (Maik 1990, 123). The material from Gdansk might indicate the preferred quality of wool garments at the coasts of the Baltic Sea during the 17th century. The s- and z-spun yarns had originally formed a surface with an even shine. Maybe this textile fragment is from a flag, which could explain the square form and the tight weave structure.

A hairy type of wool was found from the batting of the rococo petticoat from the *Sankt Michel*. The coarse wool creates a crude contrast to the beautifully quilted silk. It is difficult to explain why this type of wool was used inside the fine silk fabrics. It is worth noting that the coarse wool was not visible at all in position between two silk layers and thus the coarse wool may have been selected in order to decrease the cost of the precious petticoat.

The sock from the *Sankt Michel* was made of Fine wool, which is a product of a Merino sheep (Ryder 1987). During the 18th century, Merinos were bred in Spain, England and France (Lipson 1953, 36–45; Philipps 1997), but the Merino wool had been traded during several centuries (Lloyd 1977; Munro 1972). Because of its role in a long run trade article, the origin of the sock's wool cannot



be determined. The Merino wool is so soft that it rarely causes any itching and without doubt has felt pleasant on the feet. However, this soft wool does not stand wearing as well as the coarser wools do. Perhaps this sock was a luxury item and not knitted for a peasant's feet.

### 5.3 Tracing the dyes

Before the invention of the synthetic dyes at the end of 19th century, the textiles were dyed with natural dyes. The red dyes came mainly from madder (*Rubia tinctorium*), orchil lichens (*Orcholecia* and *Rocella* species), redwood (*Cesalpinia* species) and insect dyes (kermes and cochineal species), the blue from indigo plants and the yellow mainly from weld (Cardon 2007; Schweppe 1993). When the dating of the shipwreck textiles is taken into consideration, it is quite clear, that these textiles have been dyed with natural dyes.

The shade of colour in the fibres from the *Vrouw Maria* was very even and the original colour of the warp and weft might have been equal. This can refer to the dyeing of the fibres before spinning. The fibre types differ from each other only by the lightness: the wool fibres have more intensity and the cotton fibres are lighter in colour. The colour difference might be a result of ageing of the fibres since the different fibre types most likely have degraded at a different rate.

In addition, we might be dealing here with two different dyeing methods. Wool as a protein fibre stands better acidic dye baths and mordant dyes, but cotton as a cellulose fibre stands also alkaline dye baths. For example, orchil produces quite a similar shade of colour as cochineal, but the latter was far more expensive. The cheaper dyestuff would have been an excellent choice for the invisible weft of the warp-faced textile. However, the dyes can be ensured only with accurate additional HPLC analyses, which possibly will be done in the future.

The sock from the *Sankt Michel* contained light pink wool and the degraded silk fibres of the petticoat were pinkish orange. The colour of these fibres is close to insect dyes as well as redwood, but again, this is only a visual estimation and should be confirmed with HPLC tests. Anyhow, the fibres were so constantly colourful that they are probably from dyed textiles. The original shades of colour might have been more intense, and faded during the centuries in seawater. The brownish tint of some wool fibres of the petticoat's batting might be contamination from the submerged position. The opened scales and the bluish tint could refer to an alkaline dyeing process with indigo that stresses the fibres (Balfour-Paul 2011, 116–117, 129–130; Cardon 2007: 345–352).

### 5.4 Camlet from the *Vrouw Maria*?

The shiny fibres of the *Vrouw Maria* fragments are reminiscent of the mohair wool of an Angora goat, underwool of camel, and wool of Cashmere goat (Appleyard 1978, 33–32, 41–45). Camel and Cashmere fibres have been used for fabrics for centuries (Forbes 1987, 63; Grömer 2010, 65), but are difficult to distinguish from the sheep wool (Bergman et al. 1975, 10–11 and plates 2 and 4). The shallow scales, long scale distance and distinct lustre strongly speak here for the use of mohair fibres. The thin wool fibres in the warp and weft may be ultra-fine Merino wool.

A dictionary of trade and commerce written in the early 19th century reveals an interesting piece of information about the mohair goat's hairs. The mohair fibres were imported from the Near East to Europe, where high quality *camlets* or *camblets* fabrics were woven. These were woven in tabby weave. Some of the camlets had goat's hair in both warp and weft, some goat's hair in the warp and mixed goat's hair and silk in the weft, some sheep's wool in both yarn systems, while some had sheep's wool in the warp and "thread" in the weft. The "thread" was made of silk, flax or cotton (Mortimer 1810, 173, 613–614, 812, 1182).

Archaeologists have found a lead seal from the *Vrouw Maria*, dropped from a textile package with text "Leiden, Willem van Lelyweld" (Ehanti 2012, 63). During the 17th and 18th centuries Leiden was one of the most important centres of high quality fabric production and especially known for mixed-fibre textiles containing mohair, Merino wool as well as goat and camel wool (van der Ween

2003, 443, 450). This seal indicates that the *Vrouw Maria* had valuable Dutch cargo, but the connection of this particular researched fabric is of course uncertain. Interestingly this precious fabric was destined for Russia, which had prohibited the import of foreign fabrics in 1718 (van der Ween 2003, 452). Perhaps this camlet was bought for the Empress Catherine the Great herself, who might not have been subject to the consumption regulations.

## 6. Conclusions

Shipwreck textiles were researched to shed light on this little researched Finnish archaeological find group. The Finnish waters are full of shipwrecks, but only a few textile fragments have been found from the wrecks. The study revealed that not all supposed textiles are fabrics: the find from the *Egelskär* wreck was interpreted as remains of a sheepskin. No organic dyes were found in the HPLC analysis. The orange colour of the originally white fibres is probably iron oxide, i.e., rust from the iron bar cargo of the wreck. Indeed, in the XRF analysis, the iron (Fe) was found to be the main element of the find.

The *Lapuri* fragments were found to contain yarns spun from a primitive kind of wool. The z-twisted yarn was interpreted to be the warp, the Sz-plyed yarn the weft and the loose z-spun a darning yarn. The primitive wool type, tight twist as well as the tight ply increases the breaking resistance of the yarns and the tenacity of the fabric. Tannin was found from the yarns in a HPLC analysis, but the finding was interpreted to be a contamination from the wreck itself. In the XRF analysis, the warp and weft were found to contain iron, but the darning yarn did not have any. The fragments were interpreted to be the remains of a *smörred* sail fabric that had been treated with red ochre. The reddish darning yarn had possibly been selected on purpose to match the red ochre treated textile.

The textile from the *Mulan* wreck was found to be made of white and unpigmented wool. It contained s- and z-spun yarns that had formed an even shine to the surface of the fabric. It was suggested that this textile was a fragment of a flag. The sock from the *Sankt Michel* was found to be spun from fine Merino wool. The white wool was probably dyed with pink and red natural dyes. This colourful soft wool textile was probably quite an expensive product and not meant for a peasant's foot.

The quilted petticoat from the *Sankt Mikael* had a dark and coarse batting made of Hairy wool. This batting had possibly been dyed with indigo, because the wool fibres had a bluish hue and the scales were opened. Perhaps this crude wool was selected to decrease the cost of the quilted petticoat due to its invisible placement within two silk layers.

The red fragments from the *Vrouw Maria* consisted of several morphologically different fibres. Sheep wool, mohair, and cotton were found with the transmitted light microscope and in the control with the SEM images. The mohair fibres were present in the z-spun warp yarns. The loosely s-pun weft contained cotton and thin sheep wool fibres. Additional findings were a few possible nettle and silk fibres, which probably were not connected to the red fabric, but might be contamination from the other fabrics in the cargo. The red fibres were interpreted to be dyed before the spinning, possibly using two different dyeing methods for the different fibre types. The red textile was interpreted as an expensive, high quality camlet.

These unique finds from different time periods enrich our knowledge of shipwreck fabrics and garments found in the marine archaeological contexts in Finland. It is hoped that the underwater excavations in the future will reveal more textile finds, so that we could sharpen our picture of the trade and transport of fabrics on the maritime fairways of the Baltic Sea.

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## FIBRE ANALYSIS OF LATE IRON AGE, EARLY MEDIEVAL AND MODERN FINNISH WOOLS

### Abstract

This article compares archaeological Late Iron Age – Early Medieval Period wools found in Finland to the modern wools of Finnsheep and Finnish Jaalasheep. The archaeological finds originate from three female inhumation graves and two shipwrecks. The aim of fibre analysis is to shed light on the provenance of textiles and on wool processing. According to the analyses the archaeological textiles were made of *Hairy*, *Hairy medium*, *Generalized medium*, and *Medium* wools and one intermediate type. Moulting spring wool of modern sheep was found to be similar to the wools of some archaeological finds. It is suggested that some archaeological yarns were possibly spun directly from shed underwool staples without hand sorting.

Keywords: archaeological textiles, shipwreck textiles, Jaalasheep, Finnsheep, wool

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### INTRODUCTION

#### *The aim of study*

This article compares the wool types of some archaeological woollen fragments found in Finland to the modern wools of Finnish Jaalasheep and Finnsheep. The aim is to shed light on the provenance of finds and on wool processing through fibre analysis of archaeological and modern wool samples.

The studied archaeological textile fragments have been found in Eura Luistari, Halikko Rikala and Mikkeli Tuukkala inhumation cemeteries, but represent only a very small proportion of all textile material at these sites. In addition, this article discusses textile finds from Lapuri and Egelskär shipwrecks (Fig. 1; Table 1). The textile fragments have been dated from the Late Iron Age, i.e. from the Viking Age (c AD 800–1025) and Crusade Period (c AD 1025–1055/1300), to the Early Medieval Period (c AD 1155–1300), but are discussed together here because the transition from one period to the next was not sudden.

Wool combs have been identified in Europe as essential tools in processing primitive wool

(Christiansen 2004: 14; Gleba & Mannering 2012: 7–8) but such finds are unknown in the Finnish prehistoric material. It is possible that wool combs were made of materials that have perished or that their remains have been misidentified – or possibly wool was processed in some other way in Finland. Modern reference material is used here to understand how wool could have been processed during yarn production in prehistoric Finland.

#### *Finnish sheep wool and native breeds*

Earlier research has shown that *Hairy* and *Hairy medium* wool types predominated in the Late Iron Age in south-western Finland, and that *Generalized medium* wool was used in smaller extent. At that time pigmented brown and skimlet wool with grey, black, and white fibres were dominant (Ryder 1978; Kirjavainen & Riikonen 2005: 38; 2007: 137–8) but during the Middle Ages white was the most common colour (Kirjavainen & Riikonen 2005: 38; 2007: 137–8). Wool was plucked during the spring moulting both in the Iron Age and the Medieval Period, although shearing wool became more widespread during the Middle Ages

(Kirjavainen 2003: 268–9). Unfortunately, there are no Iron Age staple finds from Finland which would help to understand the amount of sorting and processing of wool performed during yarn production.

Finnish Iron Age sheep were probably the ancestors of Finnsheep breed, a northern short-tailed breed approximately 1000 years old (Ryder 1978; Kantanen & Tapio 2000: 22). In addition, Finland has two more native breeds, Kainuu Grey and Åland's sheep; all three are endangered species. All these breeds are genetically close to each other, but the double-coated Åland's sheep has also connections to Swedish native breeds.

The wool of modern Finnsheep and Kainuu Grey (i.e. Finnish Grey Landrace) is soft and relatively homogenous. The Finnsheep wool has a mean fibre diameter of 22.6–39.7 µm; the wool is free of kemp and the level of medullation is low (Puntila et al. 2007: 125). The *Semi-fine* wool quality has been achieved by breeding Finnsheep within the last 200 years (Vohlonen 1919: 4–5, 36–7; 1927: 63–6). The wool type of Finnsheep has been defined as a curly version of *Generalized medium* wool (Ryder 2000: 8), but the finest grade is described as *Merino* quality (Ryder 1983: 524), which is a *Fine* wool type. Today the wool of Finnsheep is white, black, grey, or brown. In general, the wool types of modern Finnsheep and Kainuu Grey are too homogenous to be used as reference material for archaeological textile finds. The mouflon coloured, double-coated Åland's sheep does not moult.

In 2005, a small and very isolated flock of Finnsheep was found in the municipality of Jaala in southern Finland (Kantanen 2007). These so-called Jaalasheep had retained archaic features, including double-coated wool with underwool, hairs and even kemp, spring moulting and more colours and patterns than modern Finnsheep (Vajanto 2011). Moulting of these sheep lasts 1–2 weeks and is not a result of nutritional changes, because in Finland the sheep are fed continuously through the winter and the moulting animals are not on the verge of starvation. The moulting habit is stronger in some genetic traits of Jaalasheep. Because of the archaic features the wool of Jaalasheep was considered as the best reference material for studying primitive wools and a parallel to archaeological wools found in Finland.

## MATERIALS AND METHODS

### *Archaeological wool samples*

Samples 1–4 were taken from twill fragments (KM 18000:2071 and KM 18000:2084) that were found in female grave 95 in the inhumation cemetery of Eura Luistari (Lehtosalo-Hilander 1982: 111–3, 402–3). The grave has been dated to the Viking Age based on the typology of bronze jewellery (Lehtosalo-Hilander 1982: 295). The textile fragments might originate from a cloak because of the coarse thread count of 6–8 yarns/cm. The fragments were found in direct contact with bronze bracelets (Kivikoski 1973: 101, Table 83).

Another twill fragment (KM 12690:168) was found in female grave 11 in the inhumation cemetery of Halikko Rikala, dated to the 11th–12th centuries AD (Hirviluoto 1992: 86; Mäntylä 2011: 223). The fragment possibly belongs to a bronze spiral ornamented cloak (Riikonen 2007: 17). Sample 6 was taken from the warp, and samples 5 and 7 from weft yarns.

Samples 8 and 9 (KM 38090:682) were found in female grave 11 in the inhumation cemetery of Mikkeli Tuukkala. The cemetery has been dated to the 14th century AD based on the typology of bronze objects (Mikkola 2009: 182, 184). The textile fragments were situated in direct contact with a bronze shoulder brooch and probably belonged to a brooch fastened *peplos* type dress typically worn by Finnish Iron Age women. Sample 8 from the 2/2 twill was tightly z-spun, but it was not possible to determine whether it was a warp or a weft yarn. The yarn seemed to be strongly orange in colour. This sample was sent to the Royal Institute for Cultural Heritage (IRPA/KIK, Belgium) for High-Performance Liquid Chromatography with Diode-Array Detection (HPLC-DAD) dye analysis to distinguish between dyeing and natural pigmentation. Sample 9 was a loose find, s-spun or untwisted, and followed the course of fibula's bone needle.

Sample 10 came from the wreck of Medieval clinker-built ship of Egelskär (SMM 1657, 342006:16). The shipwreck was found in the Finnish Archipelago Sea, but vessel's port of departure and destination harbours are unknown. The Egelskär find has been dated to the early 14th century AD based on the ship's stoneware ceramic cargo (Wessman 2007). The cargo included also a

barrel containing iron bars, which were covered with wool fibres. The fibres were identified as sheep's wool based on the scale pattern, but the find was interpreted as fleece because of the lack of any textile structures.

The remaining three samples, 11–13, were taken from two textile fragments (SMM 2592:8 and SMM 1393:27) found in the wreck of clinker-built Lapuri ship; they have been radiocarbon dated to the late 13th century AD (Möckönen 2006: 44, 58). The wooden, oaken parts of the boat might be of foreign origin due to the fact that oak is rare in Finland (Möckönen 2006). The textile fragments were found as filling between the planks (Hölttä 1993: 12–3), and probably belonged to the same fabric based on the strong similarity of warp and weft systems. The fragments had been woven in three-shafted twill, using tightly z-spun yarns (warp?) in one system and Sz-plied (weft?) in another. One of the fragments (SMM 2592:8) had been heavily repaired with brown loosely z-spun yarn.



Fig. 1. Places mentioned in the article.

Table 1. The Finnish Late Iron Age/Early Medieval archaeological textile fragments discussed in this article.

Sample	Find	Size (cm)	Structure	Function	Twist	Thread count/cm
1.	Eura Luistari KM 18000:2071	1.5 x 2	2/2 twill	warp	Sz	7–9
2.	Eura Luistari KM 18000:2071	“	2/2 twill	weft	z	6–8
3.	Eura Luistari KM 18000:2084	11.5 x 8	2/2 twill	warp	Sz	7–9
4.	Eura Luistari KM 18000:2084	“	2/2 twill	weft	z	6–8
5.	Halikko Rikala KM 12690:168	5 x 4.5	2/2 twill	weft	z	9
6.	Halikko Rikala KM 12690:168	“	2/2 twill	warp	Sz	9–10
7.	Halikko Rikala KM 12690:168	“	2/2 twill	weft	z	9
8.	Mikkeli Tuukkala KM 38090:682	2 x 3	2/2-twill	warp or weft	z	7–9/7–9
9.	Mikkeli Tuukkala KM 38090:682	0.2 x 0.4	loose yarn	decorative?	s*)	–
10.	Egelskär SMM 1657, 342006:16	3 x 3	fibres	fleece	-	–
11.	Lapuri SMM 1393:27	4 x 8	2/1 twill	warp (?)	z	5–7
12.	Lapuri SMM 2592:8	10 x 25	2/1 twill	weft (?)	Sz	6–7
13.	Lapuri SMM 2592:8	“	stitching	repair yarn	z	2

\*) or untwisted

Key: KM= National Museum of Finland, SMM= Maritime Museum of Finland

Table 2. The modern reference wools.

Sample	Personal name	Breed	Age	Sex	Length of staple	Crimps/3 cm
I	Muru	Jaalasheep	adult	ewe	underwool: 6 outer coat: 10	underwool: 12 outer coat: 2
II	Mustasilmä-Susanna	Jaalasheep	adult	ewe	underwool: 6 outer coat: 15	underwool: 12 outer coat: 0,5
III	Velho	Jaalasheep	adult	ram	underwool: 5 outer coat: 15	underwool: 12 outer coat: 0,5
IV	Jokke	Jaalasheep	adult	ram	underwool: 6 outer coat: 10	underwool: 12 outer coat: 2
V	Sioux	Jaalasheep	lamb	ram	underwool: 4 outer coat: 10	underwool: 12 outer coat: 2
VI	Sioux	Jaalasheep	adult	ram	underwool: 6 outer coat: 10	underwool: 12 outer coat: 5
VII	Eva's ewe-10	Finnsheep	adult	ewe	7	8

### Modern wool samples

Seven wool staples were shorn from one single flock of sheep – samples were taken from the shoulder area, which produces the best quality wool (see Vohlonen 1927: 57). The sampled sheep were selected to represent typical wool structures of Jaalasheep and Finnsheep (Table 2). A sampling of two ewes was done before lambing in order to get full staple instead of low quality after-lambing wool. One ram lamb was sampled at the age of 4 weeks and later as an adult to observe the growth of fleece to full scale. In addition, one ram was sampled before the spring moult and another during the moulting. To simulate the sorting of wool, underwool was removed from two staples (samples IIb and IIIb) by pulling the short and fine underwool away from the long outer coat hairs by hand.

The names of individual sheep were registered, as personal parameters are important in tracing descent lines for breeding and in researching the heritable variations of rare wool types. Thus, the sampled sheep are introduced here by names. Ewe I, *Muru*, had mostly white and very shiny underwool mixed with black hairs, smoky-bluish overall appearance and dark belly. Ewe II, *Mustasilmä-Susanna*, had white underwool, black outer coat and dark belly wool. Ram III, *Velho*, had mostly black underwool and white outer coat; he was piebald. Ram IV, *Jokke*, had mostly white underwool and white covering wool, mixed with black hairs; he was piebald with black patches. Ram V, lamb *Sioux*, was patched in white, brown and black; in addition, he had an orange overall appearance. Ram VI was the same animal, *Sioux*,

as an adult; his adult wool was generally white with some orange coarse hairs.

Finnsheep's wool has been well described in research literature (Brax 1951; Ryder 1981a: 393–4; 1983: 524; Punttila et al. 2007) and therefore only one new staple, sample VII, was taken. It came from a brown Finnsheep ewe, *Eva's ewe-10*. The wool had no distinct outer coat and was crimped, like Jaalasheep's wool. The studied flock had been shorn twice a year and the length of sampled staple was a result of five months' growth.

### Fibre analysis

Fleece of sheep evolved from primitive double-coated type of wool, containing fine underwool, hairs and kemps, into true homogenous wool with only fine wool fibres. In southern Europe, soft, homogenous, self-coloured and even white wool existed as early as 2000 years ago. In northern Europe, such wool appeared 500–1000 years ago (Nakhlik 1963; Ryder 1983; 1984; 1987; 1988; 1990a; Bender-Jørgensen & Walton 1986; Maik 1990; Walton 1988; 1989; Kirjavainen 2005a; 2005b; Rast-Eicher 2008). According to historical sources, the practice of plucking wool and the transition to shearing followed the evolution of fleece in the south (Moeller 1976: 10–11; Pliny, NH VIII: lxxiii, 190).

The coarsest fibres define the wool type (Ryder & Gabra-Sanders 1985: 128). The most archaic wool type is the *Mouflon* type, which has very fine underwool and hairy outer coat with coarse brittle kemps. In addition, there are *Hairy*, *Hairy medium*, *Generalized medium*, *Medium*, *Semi-fine* and *Fine* wool types (Table 3). There is slight variation

in the names used of different wool groups, but this research follows the names created by M.L. Ryder (1981b: 21; 1984: 20; 2000: 4–5).

Ryder’s wool categories have been criticized because the method does not take into consideration the natural variance of wool of one single sheep (Christiansen 2004: 11–8; Rast-Eicher 2008: 153–5; Brandenburg 2010: 48). It has been suggested that the wool types found in the yarns do not directly indicate the evolution of wool, but rather the wool manipulation and the level of quality the spinners set on the yarns (Christiansen 2004: 16). If the promising strontium isotope research (Frei et al. 2009) will be found suitable for Finnish textile research it can be applied to the provenance studies in the future, but for the time being Ryder’s method, despite its problems, is the only available method for wool provenance studies.

Critique has also been directed towards the incomplete and patchy information the fibre analysis produces – in practice, all fibres or yarns in a single archaeological find can never be sampled. According to Ryder (2000: 4), at least 100 wool fibres need to be measured for a valid fibre analysis. In archaeological samples it is sometimes impossible to measure more than 50 fibres due to the poor condition of decomposed fibres or the desire for non-destructive analyses. It has been estimated that 50 fibres can still give quite reliable results (Kirjavainen & Riikonen 2007: 135), but that the results of 20 analyzed fibres should be considered an approximation (Schjølberg 1992: 156).

For this research, a sample of 0.2 mm was taken from each archaeological fragment. The fibres were placed on an objective slide with distilled water as a medium. The fibres were examined with Leica DMLS (DFC 420) transmitted light microscope without dyeing. Measurements were made with Leica LAS Core V 3.6 program. Very dark fibres were defined *black*, densely pigmented brown fibres *brown*, less pigmented brown fibres *beige*, and colourless fibres *white*. Reddish-coloured fibres were defined *orange*

(Ryder 1990b: 137). In addition, the existence of medulla was observed. The plied yarns in samples 1 and 3 were opened and measured independently, but the other plied yarns were too tight or mineralized and thus both threads were analysed together.

## RESULTS

*Hairy* wool was found in archaeological samples 4 and 8, while samples 1, 6, 7, and 10 contained *Hairy medium* wool. The threads in the plied yarns 1 and 3 were made of wool types similar to each other. An intermediate type between *Hairy medium*/*Generalized medium* types was identified from samples 2, 3, 5, 9, 11 and 12. Sample 5 was heavily degraded and only a small number of fibres could be measured. Sample 13 contained *Medium* wool, but was difficult to interpret due to the small sample size. In most samples, the proportions of pigmented and medullated fibres were low, apart from sample 13. No hair roots were found (Table 4 & Appendix 1).

Sample 8 from Mikkeli Tuukala twill (KM 38090:682) contained fibres, of which the intermediate long fibres had a strong orange colour. The colour was not present in all fibres, so it was not a result of contamination with soil. According to the HPLC-DAD dye analysis, no organic dye was present or the content of dyestuff was too low to be detected (Vanden Berghe 2012). The samples from Eura Luistari and Halikko Rikala had a bluish tint and were possibly dyed.

Reference samples II, III and IV contained *Hairy* wool, while samples I, V and VI were of an intermediate type between *Hairy medium*/*Generalized medium* wools. Samples V and VI, shorn from the very same animal but at different ages, presented the most remarkable difference in the proportions of medullated fibres and in the coarsening of fibre mean thickness. Sample VII, Finnsheep wool, was determined to be *Semi-fine* wool with no medullated hairs.

Type	Range	Mean	Distribution
Mouflon	5–20, 40, 70–190 µm	12 µm, 114 µm	bimodal
Hairy (H)	5–40, 50–120 µm	30–40 µm	skewed-to-fine
Hairy medium (HM)	10–130 µm	30–40 µm	skewed-to-fine
Generalised medium (GM)	15–55 µm	25 µm	skewed-to-fine
Medium (M)	20–60 µm	30–40 µm	symmetrical
Semi-fine (SF)	15–40 µm	25 µm	symmetrical
Fine (F)	10–35 µm	20 µm	symmetrical

Table 3. Wool categories.

The researched wool samples are presented in Figure 2. In this plotting, most archaeological textiles formed a group, which includes also the sorted modern wool (samples II and III), and moulted modern wool (sample IV). The wool of Jaalasheep, as well as the wool of Finnsheep formed separate groups. Samples V (lamb's wool) and 13 (containing a small count of measured fibres) fell outside these groups.

## DISCUSSION

### *Provenance*

The examined staples from Jaalasheep's outer coat revealed that the wool types, the number of crimps and the colours do vary in a single flock of sheep. Underwool and outer coat could be differently pigmented. The proportion of medullated fibres was found to be attribute, which varies

between different sheep individuals, and a high proportion (53%) of medullated fibres can also be found in lamb's wool. The proportion of medullated hairs varied in the archaeological samples from 2 to 62%. In theory, all the researched archaeological samples could derive from local Finnish sheep, but only assuming that the flocks in the past did not produce uniform wool, and that the wools were sorted and mixed. Accordingly, the fibre analysis alone can give a false provenance determination. An imported product could be revealed by taking into consideration the archaeological context, possible atypical textile structures, and exceptional wool types.

Earlier fibre analyses made of Finnish archaeological materials had revealed that *Hairy* and *Hairy medium* wools were the most common types in the Late Iron Age Finland and that textiles were made of local wools (Ryder 1978; Kirjavainen & Riikonen 2007: 137). Samples 1 and 4 (Eura

Table 4. Statistical data of the measurements.

Sample	Type	Count of fibres (100%)	Medullated (100%)	Pigmented (100%)	Mean ( $\mu$ m)	Mode ( $\mu$ m)	VAR	SD
1a	HM	57	19	–	30	24	163	12.77
1b	HM	62	3	–	25	20	78	8.81
2.	HM/GM	87	18	–	30	26	167	12.92
3a	HM/GM	59	2	–	30	28	70	8.39
3.b	HM/GM	55	2	–	31	24	123	11.11
4.	H	61	2	–	24	20	46	6.77
5.	HM/GM	25	20	–	37	52	233	15.27
6.	HM	50	6	–	28	30	47	6.84
7.	HM	87	3	–	27	20	120	10.96
8.	H	93	4	12	24	22	84	9.18
9.	HM/GM	50	8	4	33	24	145	12.06
10.	HM	117	3	6	28	22	174	13.18
11.	HM/GM	105	14	10	36	30	249	15.78
12.	HM/GM	99	12	7	40	28	212	14.57
13.	M	26	62	38	41	42	128	11.31
I	HM/GM	88	11	26	35	32	268	16.36
II	H	113	27	38	41	22	581	24.11
IIb	H	103	4	16	29	22	155	12.47
III	H	91	18	55	34	22	292	17.09
IIIb	H	53	–	95	25	24	23	4.75
IV	H	62	3	5	27	16	136	11.66
V	HM/GM	96	53	58	37	16	278	16.69
VI	HM/GM	100	13	10	45	40	351	18.73
VII	SF	53	–	83	31	36	42	6.46

Key: VAR= variance, SD= standard deviation



Luistari; KM 18000:2071 and KM 18000:2084) as well as samples 5 and 7 (Halikko Rikala; KM 12690:168) can thus be defined as local products. The textile structure, which in Finland is the common 2/2 twill with plied warp and unplied weft (Bender-Jørgensen 1991: 96; Riikonen 2006: 14–5), supports this interpretation.

Samples 2 and 3 (Eura Luistari; KM 18000:2071 and KM 18000:2084), sample 5 (Halikko Rikala; KM 12690:168), sample 9 (Mikkeli Tuukkala; KM 38090:682), as well as samples 11 and 12 (Lapuri; SMM 1393:27 and SMM 2592:8) were spun from an intermediate wool type between *Hairy medium* and *Generalized medium*. Previously this intermediate wool type has been found in Finland in the Late Iron Age textiles from the inhumation cemetery of Tampere Vilusharju, dated to the 9th–13th centuries AD (Nallimaa-Luoto 1978: 240; Ryder 1978). These samples can be of local origin, though the 2/1 twill of the Lapuri fragments might refer to foreign origin (Tomanerä 2006: 45).

Only a little research has been done on the 14th century AD cemetery finds of Finnish inland, and it is unknown what kind of wool was available in these areas during that period. Sample 8 (Mikkeli Tuukkala; KM 38090:682) was defined to be most probably of local origin due to the *Hairy* wool. This kind of weather protective, double-coated fleece has been important to the northern sheep breeds (Christiansen 2004: 14). For example, in Greenland, contemporary archaeological yarns have been spun from the wool of double-coated sheep (Østergård 2004: 83–9) and *Hairy* and *Hairy medium* wools have also been found to be predominant in Medieval Turku in south-western Finland (Kirjavainen 2005a: 136–7; Kirjavainen & Riikonen 2007: 137).

Sample 13 from the Lapuri textile (SMM 2592:8) was made of *Medium* wool, but the count of measured fibres was small and might give a misleading picture of fibre distribution. The sample can be of foreign origin; in Medieval Europe, the wools were mainly of *Generalized medium* and *Medium* types, and coarser wool existed only rarely (Ryder 1984: 26; Maik 1990: 123; 1998: 220–1). Furthermore, *Medium* type wool has been recognized in imported textiles from Medieval Turku (Kirjavainen 2005a: 137, 142–3).

Medieval raw wool staples found in Turku, most probably of local origin, were mainly skimmlet with brown fibres. One completely white

staple was also found, and, in addition, white wool existed in yarns (Kirjavainen 2005a: 136, 140). Thus the almost white *Hairy medium* wool sample 10 from the Egelskär fleece (SMM 1657, 342006:16) might derive from local Finnish sheep flocks. Alternatively, because of its archaeological context in a trader, the Egelskär fleece can be an imported product from some other part of the Baltic Sea coast where double-coated sheep were bred.

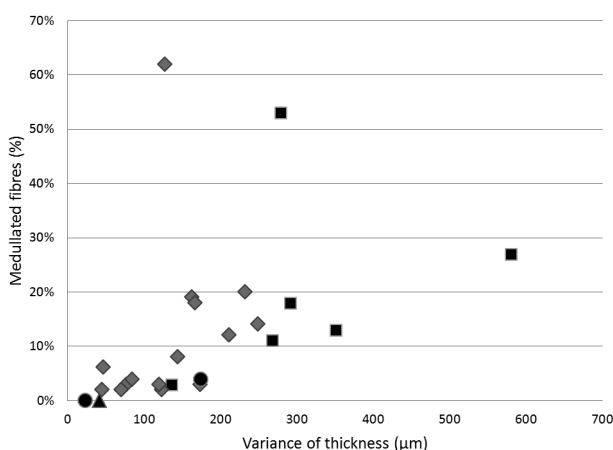
### *New insights from modern wool*

Prehistoric lamb's wool probably differed from the wool of an adult sheep, but without prehistoric lamb and adult wool staples, ideally from *one single* sheep, it is almost impossible to determine the degree of change, and the observations might also reflect the non-uniform wools of prehistoric fleeces (Ryder 1978; 1988). When observing the fibres in lamb's wool in sample V, it was noted that naturally phaeomelanin-pigmented orange wool fibres could easily be misidentified as dyed fibres in visual microscopic examination – possibly also the orange fibres in sample 8 contained phaeomelanin, which still exists in some sheep breeds (Ryder 1983: 545; 1990b: 137, 148; 1991: 59).

Nowadays only ewe's wool is commonly spun, because ram's wool has a strong odor. However, it is possible that ram's wool was also spun in the past to diminish the amount of wasted wool. Ram's wool in sample VI has a mode of 40 µm in underwool, in addition to a few coarse hairs typical of *Hairy medium/Generalized medium* wool. In ewe's wool in sample I of the same wool type, the mode is 32 µm. Thus a non-typical histogram with coarse mean and mode could facilitate the identification of ram's wool.

Sorting experimentation made with the modern wool, samples IIb and IIIb (Table 4 & Appendix 1), revealed that it was possible to sort underwool (less than 50 µm) from outer coat with a high degree of accuracy. This sorted wool included only a few medullated hairs. Underwool consisted of approximately 70–80% of the total original fibres in the fleeces. The larger number of hairs in sample IIb could be explained by less careful sorting and this could also be the explanation for hairs in the archaeological samples. Alternatively, the hairs in archaeological samples could be explained to be a result of intentional preserving or adding of long hairs, which not only increases

Fig. 2. Researched wools compared by variance and diameter range. Archaeological wool – grey rhomboid, reference wool of the Jaalasheep – black square, sorted wool of the Jaalasheep – black disc and wool of the modern Finnsheep – black triangle.



the warps' resistance to breakage (samples 1, 3 and 6), but also diminishes the amount of wasted wool (samples 2, 4, 5, 7, 8, 9, 11 and 12).

It has been suggested that the coarsest fibres were removed during the spring moulting period when different wool types could be plucked separately due to their different intervals of moulting (Ryder 1983: 49). Furthermore, Ryder (1993: 310) has described that in the sheep breeds of Orkney and Shetland the coarse hairs shed later than wool. Jaalasheep moult differently: first, the coarse hairs fall out, and then the finer fibres of underwool, as can be seen in sample IV.

The experiments raise a question, whether moulted wool was sorted at all by humans in the Late Iron Age and Early Medieval Finland. Perhaps the underwool was collected during moulting, after the sheep had shed the coarsest hairs. Especially archaeological samples 11 and 12 can be interpreted to have been collected during spring moult and spun directly from staple, i.e. according to a method suggested to be the most archaic manner in yarn making (Ryder 1969: 500) (Fig. 2 & Appendix 1).

Jaalasheep moult only once a year in the spring, but are shorn again in the late autumn. Traditionally, Finnsheep has been shorn 2–4 times per year; the autumn wool is of the best quality with the longest fibres (Vuorela 1975: 472). Until the beginning of the 20th century AD in eastern Finland, the shorn wools were mixed carefully and beaten with wooden sticks or an ancient tool called *savitsin*, which were later replaced by hand carders (Vuorela 1975: 472–3; Forbes 1987: 11). Fragments of Medieval wool beaters have been found in Finland, but no wool carders or wool combs have been discovered (Kirjavainen

2003: 269). Perhaps the Iron Age Finnish wool was plucked in the spring time during the moult of the underwool, which was ready for spinning per se. The wool shorn in the autumn got a different quality; it contained both the fibres from the underwool and the coarse outer coat hairs. The lack of wool combs suggests that the autumn wool was sorted by hand. Possibly the staples were not beat with *savitsin*, but with simple wooden sticks, which are easily perishable and difficult to identify from the archaeological material.

## CONCLUSION

Some Late Iron Age and Early Medieval textiles found in Finland were examined in this study. The samples were found to contain *Hairy*, *Hairy medium*, *Generalized medium* and *Medium* wools as well as intermediate types between *Hairy medium/Generalized medium* wools. No clear evidence of the evolution of sheep fleece towards softer, homogenous modern wools was found.

The samples from Eura Luistari (KM 18000:2071 and KM 18000:2084), Halikko Rikala (KM 12690:168) and Mikkeli Tuukkala (KM 38090:682) cemeteries were defined as being of local origin due to the presence of *Hairy* and *Hairy medium* wools and an intermediate type between *Hairy medium/Generalized medium* wools. These wool types have also parallels in other Finnish archaeological material.

The warp and weft yarns of the Lapuri fragments (SMM 2592:8 and SMM 1393:27), made of *Hairy medium/Generalized medium* wool, were defined as possibly local products, although the textiles are 2/1 twill, which is rare in Finnish archaeological textile material. The repair yarn

from one of the Lapuri fragments (SMM 2592:8), made of *Medium* wool, might be of foreign origin. The fleece from the Egelskär shipwreck (SMM 1657, 342006:16) was defined as *Hairy medium* fleece, either local or imported, because of its archaeological context in a trade vessel.

The fibre analyses revealed that the wool of modern Jaalasheep was comparable to the Finnish archaeological wools. What was notable in the wools of Jaalasheep was that the underwool and outer coat could be differently pigmented; the proportion of medullated fibres varied between individuals; and a high proportion of medullated fibres could also be found in lamb's wool. In the wool samples taken from one single Jaalasheep, orange wool was found in both adult's and lamb's wool. The orange fibres in archaeological textiles might thus contain the rare pigment of phaeomelanin, especially when no dyes can be detected in the HPLC-DAD analysis. Double-coated wool with relatively coarse underwool could indicate the use of ram's wool.

The presence of hairs in the archaeological textiles could be explained by a lack of careful sorting. In addition, the hairs can be seen as a sign of intentional preserving or adding of long hairs, which not only diminishes the amount of wasted wool, but also increases the yarn's resistance to breakage. An alternative explanation comes from the modern reference staple collected from naturally moulted wool with a distribution close to the hand-sorted staples. Accordingly, some prehistoric wool material could have been collected during moulting time after the shed of hairs and spun directly from staples; some wool that was shorn in the autumn may have been sorted by hand.

Experimental work with modern reference wool offers a rich source of possibilities for wool manipulation research starting from plucking. Such research can also provide new insights on wools and yarns from archaeological contexts.

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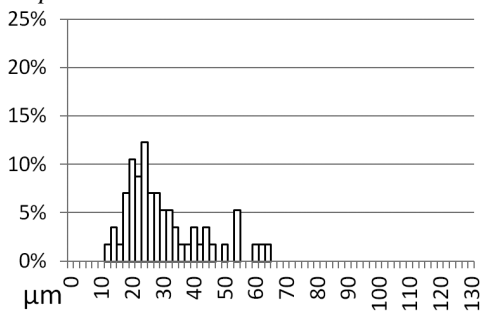
Walton, P. 1988. Dyes and Wools in Iron Age textiles from Norway and Denmark. *Journal of Danish Archaeology* 7: 144–58.

Walton, P. 1989. *Textiles, Cordage and Raw Fibre from 16–22 Coppergate*. The Archaeology of York: The Small Finds 17(5). Council for British Archaeology, London.

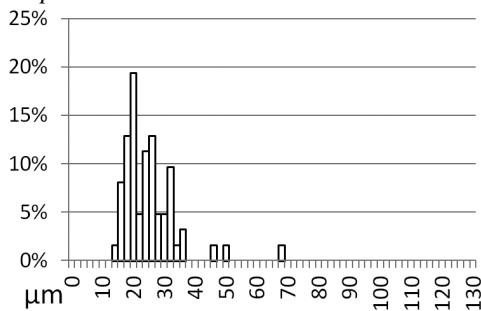
Wessman, S. 2007. Ship fragments on the seafloor – what do we know about medieval seafaring in Finland. In V. Immonen, M. Lempiäinen & U. Rosendahl (eds.), *Hortus Novus. Fresh approaches to medieval archaeology in Finland*: 140–50. Medii Aevii Finlandiae XVI. Suomen keskiajan seura, Turku.

## APPENDIX 1. MEASUREMENTS PRESENTED AS HISTOGRAMS

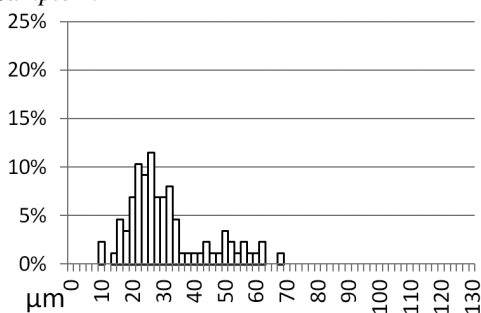
Sample 1a.



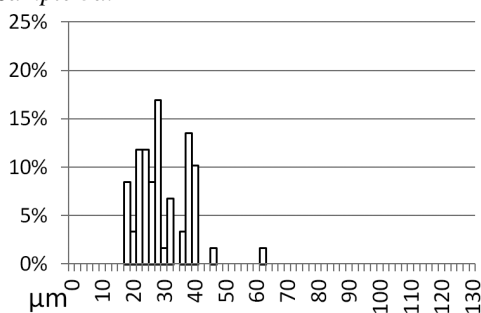
Sample 1b.



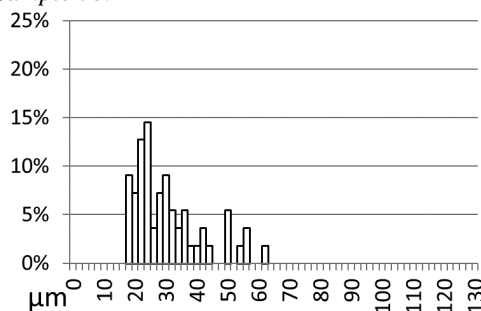
Sample 2.



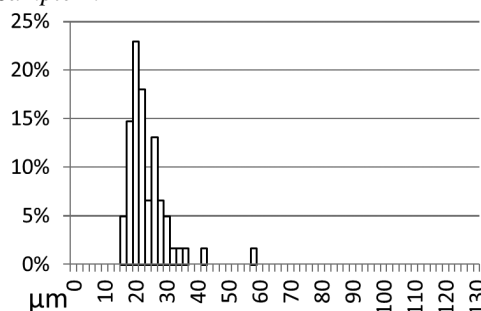
Sample 3a.



Sample 3b.

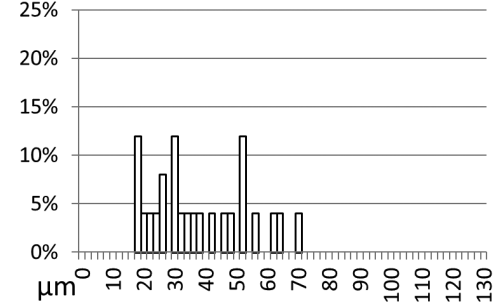


Sample 4.

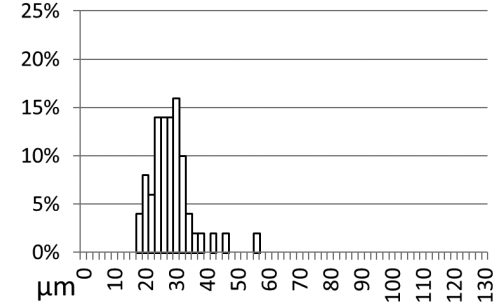


□ white    ▨ orange    ▩ beige    ▤ brown    ■ black

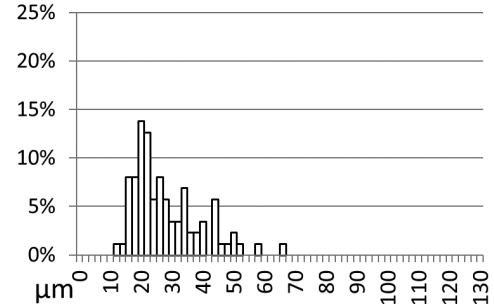
Sample 5.



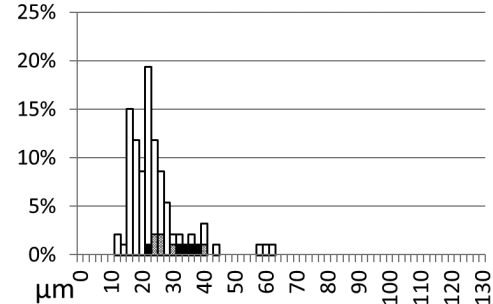
Sample 6.



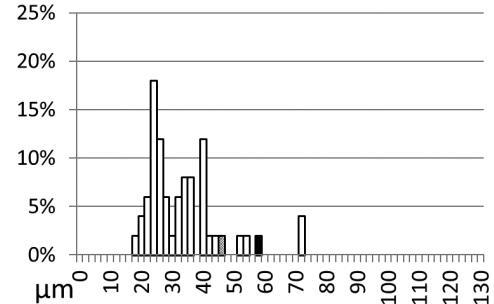
Sample 7.



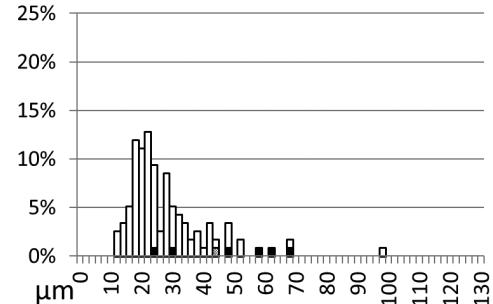
Sample 8.



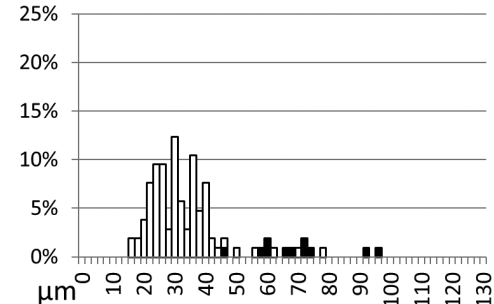
Sample 9.



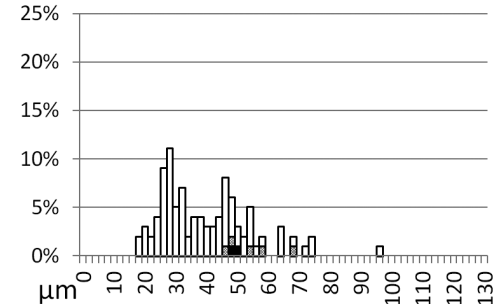
Sample 10.



Sample 11.

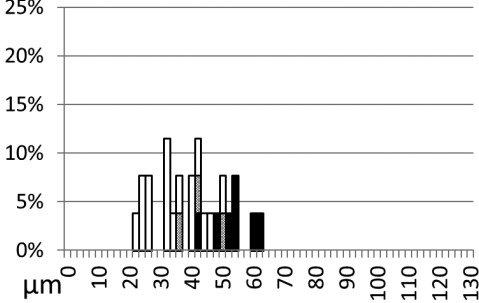


Sample 12.

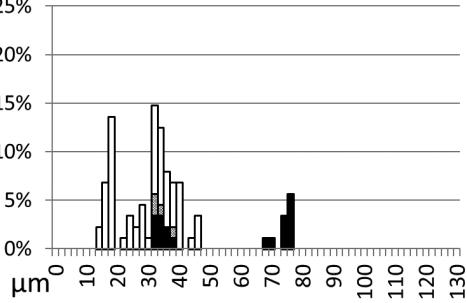


□ white    ▨ orange    ▩ beige    ▪ brown    ■ black

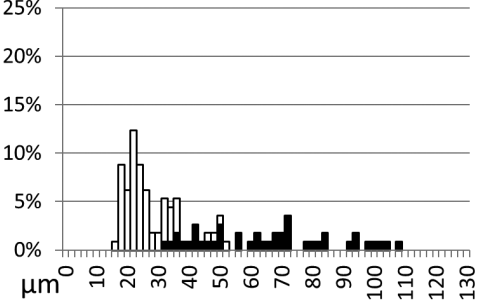
Sample 13.



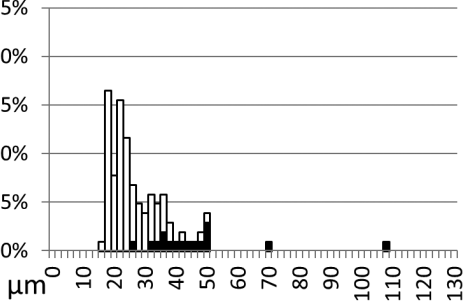
Sample I.



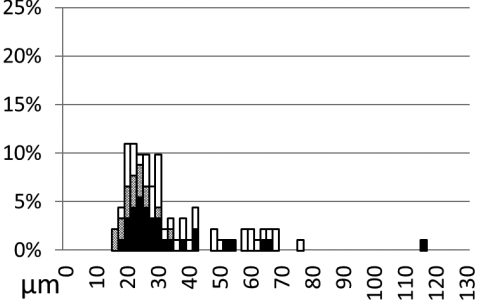
Sample II.



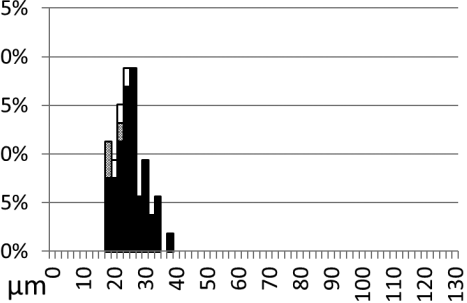
Sample IIb.



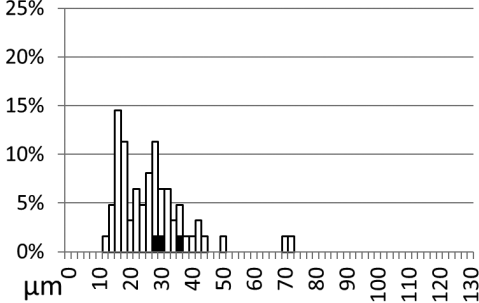
Sample IIIa.



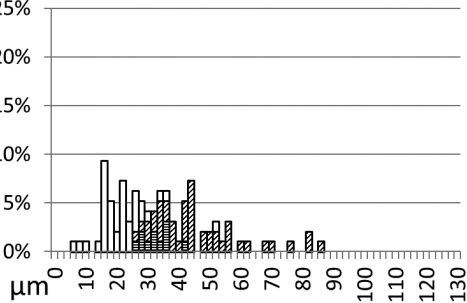
Sample IIIb, sorted wool.



Sample IV.

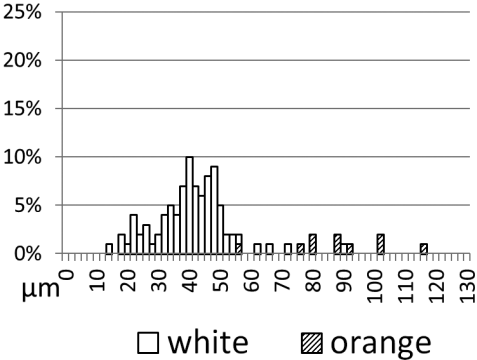


Sample V.

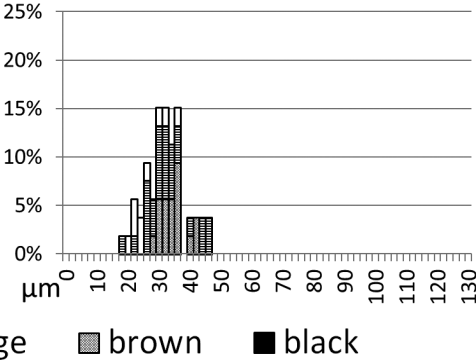


□ white    ▨ orange    ▩ beige    ▪ brown    ■ black

Sample VI.



Sample VII.





# Textile standards in experimental archaeology

Krista Vajanto

## ABSTRACT

*This article sheds light to the textile standards that are testing methods of the textile industry. The breaking resistance of yarns, the colour fastness for perspiration and the tex value are discussed especially from the viewpoint of experimental archaeology. Standards for these parameters are applied to the test material made of Finnish machine- and hand-spun wool yarns, as well as yarns dyed with three different dyeing methods and three natural dyes: i.e., Dyer's madder (*Rubia tinctorum*), alder buckthorn (*Rhamnus frangula*), and rock tribe (*Lasallia pustulata*). The hand-spun yarns were found to be stronger than machine-spun and the tenacity correlated to the dyeing methods. Especially the double-coated wool suffered from dyeing with the boiling method, but retained the strength when dyed in a fermented alder buckthorn bath. The colour fastness for perspiration was found to be excellent in the yarns dyed with lupine and rock tribe that often are not valued by modern dyers due to low light fastness. The study offers new possibilities to understand the selections made for the yarns and dye materials in the past.*

*Keywords: tex value, breaking resistance, colour fastness for perspiration, wool, natural dyes, fermentation*

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## 1. Introduction

The *textile standards* are test methods made for the textile industry to test and compare different textile products and certain parameters with relatively simple test procedures. There are worldwide ISO standards, European EN standards, American AATCC and ASTM standards, and other national standards (*ISO.org*; Saville 2000, 298–299; Kadolph 2007, 42). However, textile standards are quite unknown in textile archaeological research. When researching replica material based on archaeological finds, it has been found that textile standards can give useful knowledge that is suitable to archaeological textile research. With a standardised test protocol of the empiric test methods, it is possible to produce comparable data that answers the demand for the repetitive and accurate research methods sought for experimental textile archaeology (Andersson Strand 2010, 1–3).

The basic element of most of the archaeological textiles is a yarn. Often the yarns have been studied by thickness, twist or ply as well as the spinning and plying angle (Seiler-Baldinger 1994, 3–4). To understand the differences between the hand-spun and machine-spun yarns, the replica yarns were measured with ISO 2062:2009 textile standard. This textile standard records the *breaking resistance* as well as the strain and the tenacity of the yarn. The *tex value*, presented in the textile standard ISO 1144:1973, was applied to find thin wool yarns that are near each other by linear density (Tevasta 2009, 10–12; *ISO.org*). The same textile standards were applied in order to study the effect of a dyeing method to the tenacity of a yarn.

The textile standard ISO 105-E04:2008 was applied to find out the *colour fastness* of the natural dyes *for perspiration*. Sweat stains can be considered as wear marks that can tell us about the history of a textile especially when a textile is large enough and armpit areas are present. For example, it can be questioned whether the funeral textiles had been made specifically for the funeral ritual or had been worn in the everyday life.



1. Espoo
2. Lohja
3. Eno
4. Archipelago Sea

Map 5. Placenames mentioned in the article of Vajanto. Illustration: K. Vajanto.

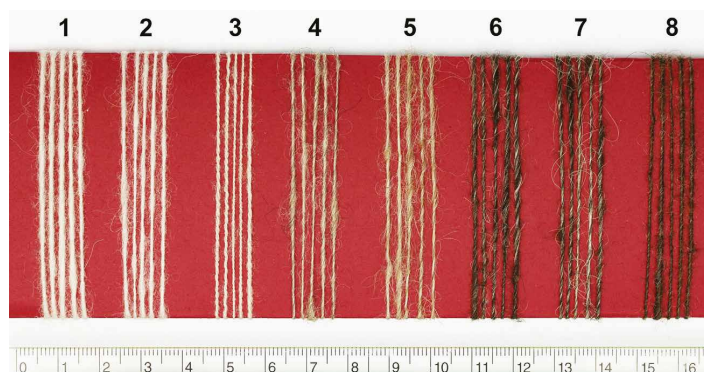


Fig. The hand-spun yarns I–VIII tested with the textile standard ISO 2062:2009. J. Markkanen.

## 2. Materials

### 2.1 Wool yarns

Eight different wool yarns were selected for the breaking resistance test (Yarns I–VIII, Table 1 and Fig). The yarns were tested not only as undyed, but also as dyed with three different plant dyes with different dyeing methods. Yarn I was machine-spun Finnsheep wool by *Pirtin kehräämö* and yarn II was by *Virtain villa*; both are available from Finnish yarn manufacturers. Yarns I, II, as well as the hand-spun yarn III contained Finnsheep wool. Miscellaneous machine-spun yarns, made of white Finnsheep wool, were selected for the colour fastness for perspiration test (Yarns 1–15, Table 2). The Finnsheep wool is homogenous and of Semi Fine (SF) type (Ryder 1974, 1984, 1987; Vajanto 2013b). Yarns IV–VIII (Table 1) were spun from double-coated wool of the Finnish Jaalasheep. The wool is a primitive type with under wool and outer coat hairs (Manninen 2012, 13; Vajanto 2011a; 2013b). The wool types of yarns IV–VIII were Hairy medium/Generalised medium (HM/GM), Hairy medium (HM) and Hairy (Table 1), of which the Hairy type (H) contains the most distinct populations of underwool and outer coat fibres (Ryder 1974, 1984, 1987; Vajanto 2013b).

Before the hand spinning, the wool staples were washed gently without any detergents by leaving the staples in fresh water for some days at room temperature; they were then dried on a horizontal level. All of the hand spun yarns were spun with a drop spindle with a whorl of 17 g and spindle shaft of c. 27 centimetres. Yarns I and II were machine-carded wool. Yarns III, V, VI and VIII were combed with small wool combs, but yarns IV and VII were carded with hand carders. The spinners were skilled and able to produce thin and even yarn from different wool types with a speed of 37–57 metres per hour.

### 2.2 Dyes

According to Finnish folklore, all the selected dyes have been used by folk people in Finland from the late 19th to the early 20th centuries. The folklore was mainly collected in surveys conducted by the scholars of The Finnish Literature Society and carried out by interviewing old folk people about almost forgotten old habits and skills. Another important source of plant folklore is the herbarium, *Flora Fennica*, written by Elias Lönnrot in 1860. It was the first herbarium written in Finnish, and contains abundant knowledge of the medical, dye and edible plants and folkloric variants of plant names.

According to the folklore, the red dyes were obtained from the roots of local bedstraws, i.e. Lady's bedstraw (*Galium verum*) and northern bedstraw (*Galium boreale*) and imported roots of Dyer's madder (*Rubia tinctorium*). Red was also obtained from the roots of the common tormentil (*Potentilla erecta*), bark of alder species (*Alnus glutinosa* and *Alnus incana*), alder buckthorn (*Rhamnus frangula*), and bark of silver birch (*Betula pendula*).<sup>1</sup>

<sup>1</sup> MV:KTKKA. Hahti, Kerttu 1936: Kasveilla värjäys, 29–39; SKS/KRA. Inkeri. Mannonen, Ulla 12 d, h, i, j, s: 4409/1937; SKS/KRA. Kirvu. Pärssinen, Sirkka E 142: 14–16/1938; SKS/KRA. Orivesi. Hörsänä, Hugo 3058/1953

Table 1. The technical data of undyed yarns researched in the breaking resistance test using the ISO 2062:2009 textile standard.

No.	Wool	Wool type	Carding/Combing	Spinning	Twist	Spin/ply angle (°)	Diameter (mm)
I	Finnsheep white	SF	Machine carders	Machine	z	30	1
II	Finnsheep white	SF	Machine carders	Machine	z	30	0.75
III	Finnsheep white	SF	Wool combs	Hand	Sz	40/55	0.5–1
IV	Finnish Jaalasheep grey	HM/GM	Hand carders	Hand	z	20	0.5–1
V	Finnish Jaalasheep beige	HM	Wool combs	Hand	z	20	0.5–1.5
VI	Finnish Jaalasheep black and white	H	Wool combs	Hand	z	20	1–1.5
VII	Finnish Jaalasheep black and white	H	Hand carders	Hand	z	20	1–1.5
VIII	Finnish Jaalasheep brown	HM/GM	Wool combs	Hand	z	33	0.5–1

The folklore records show that yellow came from evergreen plants such as heather (*Calluna vulgaris*), wild rosemary (*Rhododendron tomentosum*), bog rosemary (*Andromeda polifolia*), and crowberry (*Empetrum nigrum*) (Linnilä et al. 2002, III/231, 245). Bright yellow came from the leaves of the silver birch (*Betula pendula*), especially when collected in early spring.<sup>2</sup>

The fresh, blue berries of the alder buckthorn (*Rhamnus frangula*), blue cornflowers (*Centaurea cyanus*)<sup>3</sup> and purple flowers from heartsease (*Viola tricolor*) were used for shades of blue and turquoise (Linnilä et al. 2002, III/91–92). For this study the turquoise was taken from everywhere abundantly growing lupine (*Lupinus polyphyllus*) to protect the more rare species (Vajanto 2013a, 7–9.)

Natural alum mordant was made from club moss (*Lycopodium species*)<sup>4</sup>, which was boiled for several days (Hassi 1981: 46). Crottle (*Parmelia saxatilis*)<sup>5</sup> was used for browns and rock tripe (*Lasallia pustulata*) was used for purple (Warg 1790; Westring 1805: 160–183; Casselman 2001, 11; Tetri 2013, 172–173).

## 2.3 Dyeing methods

Because there are slight, but possibly important variations, the dyeing recipes are explained here in detail to encourage other researchers and dyers to repeat them. Before dyeing, the yarns were not washed with detergents, just wetted. The water was Finnish tap water, which is pure, soft and has a pH value of 7.5–8. After dyeing, all the yarns were rinsed with lukewarm water, without any detergent and dried avoiding direct sunlight.<sup>6</sup>

### 2.3.1 Fermented tannins

A dye bath was prepared with the fermentation method from plants and wood ash lye. Two litres of birch wood ash was collected to a bucket from a sauna stove. The lye was prepared by pouring eight litres of boiling water over the ash (Hassi 1981, 25–26; Dean 1999, 58; 2007, 38). After three days the lye had a pH value 10 and it was sieved.

Then dry, chopped bark of alder buckthorn and chopped dry birch bark were added to the buckets that contained the sieved lye. The ratio of the plant materials and lye was 1:10. The fresh and chopped roots of tormentil were used with the same ratio. The fermentation process of the dye baths took four weeks at room temperature and the pH value of the baths decreased from 10 to 6. Then the skeins (Yarns 1–3, Table 2) were added to these bubbling baths that had the odor of red wine and were dyed for two weeks at room temperature (Vajanto 2010a; Vajanto 2011b, 287–231; Vajanto 2011c, 34–36).

2 SKS/KRA. Orivesi. Hörtjänä, Hugo 3058/1953

3 SKS/KRA. Inkeri. Mannonen, Ulla 12 d, h, i, j, s: 4409/1937; SKS/KRA, Hausjärvi. Salminen, Kaarina E 177: 5/1947.

4 SKS/KRA. Rautu. Snellman, Kirsti E 134: 6–7/1936

5 SKS/KRA. Kirvu. Pärssinen, Sirkka E 142: 14–16/1938; SKS/KRA. Rautu. Snellman, Kirsti E 134: 6–7/1936

6 Northern bedstraw roots, silver birch bark, rock tripe, common lupine flowers, silver birch leaves, heather, crowberry and wild rosemary were collected in Espoo. Chopped Dyer's madder and alnus buckthorn were bought from TetriDesign dye shop [www.tetridesign.fi](http://www.tetridesign.fi), crottle was collected in the Archipelago Sea, clubmoss in Eno and common tormentil roots in Karjaa. See Map 5 for the sites of plant collection.

Table 2. CIELAB values of the dyed yarns before the colour fastness for perspiration test ISO 105-E04: 2008. Photos: J. Markkanen

No.	Plant	CIELAB (D 65)			
1.	Alder buckthorn ( <i>Rhamnus frangula</i> ), bark	L* 46.09 a* 23.10 b* 38.26	C* 44.70 h* 58.88		
2.	Common tormentil ( <i>Potentilla erecta</i> ), roots	L* 37.09 a* 25.87 b* 22.17	C* 34.07 h* 40.59		
3.	Silver birch ( <i>Betula pendula</i> ), bark	L* 48.06 a* 17.86 b* 13.44	C* 22.35 h* 36.97		
4.	Rock tripe ( <i>Lasallia pustulata</i> ), whole lichen	L* 24.68 a* 18.83 b* -7.59	C* 20.31 h* 338.04		
5.	Crottle ( <i>Parmelia saxatilis</i> ), whole lichen	L* 33.02 a* 22.27 b* 33.51	C* 40.23 h* 56.39		
6.	Dyer's madder ( <i>Rubia tinctorium</i> ) roots + Club moss ( <i>Lycopodium</i> ), whole plant	L* 32.14 a* 32.03 b* 30.11	C* 43.96 h* 43.23		
7.	Dyer's madder ( <i>Rubia tinctorium</i> ), roots	L* 47.82 a* 33.15 b* 34.41	C* 47.78 h* 46.07		
8.	Northern bedstraw ( <i>Galium boreale</i> ), roots	L* 42.09 a* 32.84 b* 27.96	C* 43.13 h* 40.41		
9.	Common lupine ( <i>Lupinus polyphylus</i> ), flowers	L* 39.87 a* -10.33 b* 11.61	C* 15.54 h* 131.67		
10.	Silver birch ( <i>Betula pendula</i> ), leaves	L* 59.70 a* 6.42 b* 68.28	C* 68.58 h* 84.63		
11.	Heather ( <i>Calluna vulgaris</i> ), whole plant	L* 61.98 a* 6.50 b* 61.09	C* 61.43 h* 83.93		
12.	Crowberry ( <i>Empetrum nigrum</i> ), whole plant, collected in winter	L* 50.03 a* 14.97 b* 27.03	C* 30.90 h* 61.02		
13.	Crowberry ( <i>Empetrum nigrum</i> ), whole plant, collected in summer	L* 61.87 a* 4.21 b* 45.94	C* 46.13 h* 84.77		
14.	Wild rosemary ( <i>Rhododendron tomentosum</i> ), whole plant	L* 58.83 a* 7.45 b* 52.68	C* 53.21 h* 81.86		
15.	Bog rosemary ( <i>Andromeda polifolia</i> ), whole plant	L* 55.79 a* 12.11 b* 61.83	C* 63.00 h* 78.91		

### 2.3.2 Urine bath

A dye bath was prepared from dried rock tripe and human urine. First, the urine was stored for ten months at 4°C under a lid and two months in a warm storage in a container without a lid. Finally, it reached a pH value of 10. The dyestuff was yielded from 100 g of dried rock tripe by soaking the lichen in three litres of fermented human urine at the temperature of 4°C and in darkness. This took three months. After that, the skein (Yarn 4, Table 2) was dyed in the dye bath that still contained the lichen material. The dyeing took two weeks in darkness at a temperature of 4°C (Vajanto 2010b).

### 2.3.3 Lichen bath with no added mordant

No chemicals or additional natural mordant is needed for a crottle dye bath, which itself works as a mordant. The skein (Yarn 5, Table 2) was just boiled one hour with dried crottle using 200 g of lichen and ten litres of water (Goodwin 2003, 90–91; Hassi 1981, 122).

### 2.3.4 Alum mordant baths

Club moss is a natural source of alum. A mordant bath was prepared from 200 g of fresh plant and ten litres of water. During one week, the dye bath was heated once a day to 80°C, but kept meanwhile at a temperature of 30–50°C. Slowly, the bath attained a lemon juice odor and pH value of 5. The skein (Yarn 6, Table 2) was added to the sieved bath and mordanted by boiling for 45 minutes (Hassi 1981, 46). After mordanting, the yarn was dyed by boiling it in eight litres of water with a temperature of 90°C for 45 minutes. The ratio of dry plant material and yarn was 2:10. The remaining yarns were mordanted by boiling them for 45 minutes with 12 g of alum and 4 g of cream of tartar (Yarns 7–15, Table 2).

The mordanted yarns (Yarns 6–15, Table 2) were *not* rinsed after mordanting. The mordanted yarns 7–9 (Table 2) were dyed with eight litres of water with fresh, cleaned and chopped roots of northern bedstraw, or fresh flowers of purple lupine or fresh silver birch leaves. There the ratio of fresh plants and yarns was 2:1. For the mordanted yarns 10–15 (Table 2), the dye baths were prepared by boiling 300 g of fresh plant materials in eight litres of water for 1.5 hours. After this, the baths were sieved and cooled down. The mordanted yarns were dyed in the dye baths by boiling them in 90°C for 45 minutes (Hassi 1981, 48, 52–54).

## 3. Research methods

### 3.1 Breaking resistance

The *breaking resistance* is measured using the ISO 2062:2009 textile standard (Tevasta 2009, 382–391, *ISO.org*). It tells how strong a yarn is, how large a load is needed to break the yarn, and how much the yarn can be stretched before it breaks (Saville 2000, 115–118). The *tenacity* (cN/tex) of the yarn is the ratio of the breaking force (cN) and the *tex value* (tex).

The tex value, ISO 1144:1973, expresses the linear density of a yarn, in other words the mass per unit of length (i.e., 1 g/1000m = 1 tex) (Taylor 1994, 63). The resulting tenacity value of the breaking resistance test is dependent on such factors as the thickness of the yarn, spin and ply properties, and type of fibres. Therefore, the values measured from the individual fibres vary from the values measured from the yarns. For the individual fibres, the textile standard ISO 5079:1995 is recommended (*ISO.org*).

The breaking resistance test was made with SDL Testometric MTCL 250 that is a Constant Rate of Elongation (CRE)-type apparatus. The yarn was inserted to a tension between two gauges that stretched the yarn (Saville 2000, 132). The yarns were pre-tensioned with a 50 g weight. All the sampled yarns were 25 centimetres in length and dry. The *Strain* of a yarn was observed at its breaking point. The measurement was stopped manually at the point of the break. The measurement was made until the point, at which the last fibre of the measured yarn broke.



For industrial purposes, the textile standard ISO 2062:2009 requires 50 measurements for unplied yarns and 20 for plied ones. Unfortunately, this requirement was too stringent for the unique hand-spun and plant-dyed yarns that formed most of the research material. Because of this, each yarn was measured only five times. However, the values measured from each yarns were very consistent. The results can be taken as an example of the actual method as well as a source of inspiration for the understanding of the behaviour of different types of yarns.

### 3.2 Colour fastness for perspiration

Sweat tolerance of dyes was measured using the textile standard ISO 105-E04: 2008 (Tevasta 2010, 261–275; *ISO.org*). For the test, two kinds of artificial human sweat were prepared according to the test protocol (Saville 2000, 252–253; Taylor 1994, 204). The acidic sweat had a pH value of 5.5 and the alkaline sweat a pH value of 8.

The dyed yarn samples were sewn within two white adjacent fabrics (Saville 2000, 246). The recommended adjacent fabrics are determined in the textile standard ISO 105-F01–F07:2009, that contains fabrics made from both natural and synthetic fibres. For this research single-fibre adjacent fabrics of wool (ISO 105-F01:2009) and cotton (ISO 105-F02:2009) were selected, because these materials are also known in archaeological materials (Gleba and Mannering 2012, 5–7). The acidic and alkaline sweat was infiltrated to the test samples by following the ISO test protocol. After this, the samples were placed in the test device under the necessary pressure and kept in the warmth of 37°C for four hours.

The results were valued from the dried yarns with so-called *grey scales* using the textile standard ISO 105-A03:1993 (Saville 2000, 245; Taylor 1994, 198–199; *ISO.org*). The change of colour was valued with a card that has five steps from light grey to dark grey and staining with a card that has five steps from white to black. In addition, the values can be announced with half steps, as in 1/2, 2/3, 3/4, 4/5. The best result with no colour change or staining received the value 5, and the worst the value 1.

In order to get objective measurement data about the colour changes, all the colour values were also measured in the CIELAB colour space. The measurements were done with the Minolta CM 2600D Spectrometer, with the Spectra Magic programme and the D65 illuminant (Trotman 1984, 548). The measured area was eight millimetres in diameter.

### 3.3 Test conditions

The test conditions are instructed in the descriptions of the ISO 139:2005 textile standard. In practice, it is not always possible to achieve recommended test environment that has relative humidity of 65% and a temperature of 20°C (*ISO.org*; Kadelph 2007, 83). For this study, the environment had the relative humidity of 45% and the temperature of 22°C. The tests were carried out in similar conditions to each other; thus the results are comparable.

Wool and other fibres behave in relation to humidity and temperature. Dry wool is stronger than wet, but wet wool can be extended more (Saville 2000, 27–28, 135–136). The yarns were not pre-conditioned due to an incomplete test environment. The skeins were loosened and let to rest in the test environment for 24 hours. If the measurements had been carried out in a moister standard atmosphere, the measured breaking resistance values could have been slightly smaller and strain values higher.

## 4. Results

### 4.1 Stronger and weaker yarns

The data of the measurements is presented in Table 3. The values are presented as averages of five measurements and rounded as recommended in the textile standard. The highest forces were needed to break the hand spun yarns. In general, the high tenacity seemed to correlate with the primitive type of wool, combing, high degree of twist and ply as well as the fermentation dyeing method.

Table 3. Results of the breaking resistance test (ISO 2062:2009).

No.	Yarn, wool and dye	Tex value	Load at breaking point (cN)	Strain (%)	Tenacity (cN/tex)
I Finnsheep, machine spun, machine carded					
Ia	Undyed	220	326	60	1.5
Ib	Alder buckthorn	184	366	53	2.0
Ic	Dyer's madder	182	287	50	1.6
Id	Rock tribe	164	329	55	2.0
II Finnsheep, machine spun, machine carded					
IIa	Undyed	125	211	51	1.7
IIb	Alder buckthorn	138	441	48	3.2
IIc	Dyer's madder	132	127	52	1.0
IId	Rock tribe	134	252	41	1.9
III Finnsheep, hand spun, combed, plied					
IIIa	Undyed	109	530	11	4.9
IIIb	Alder buckthorn	111	656	17	5.9
IIIc	Dyer's madder	113	567	20	4.9
IIId	Rock tribe	113	539	20	4.8
IV Finnish Jaalasheep, hand spun, carded					
IVa	Undyed	159	620	48	3.9
IVb	Alder buckthorn	124	622	31	5.0
IVc	Dyer's madder	155	407	29	2.6
IVd	Rock tribe	150	389	55	2.6
V Finnish Jaalasheep, hand spun, combed					
Va	Undyed	186	460	61	2.5
Vb	Alder buckthorn	185	323	54	1.8
Vc	Dyer's madder	191	324	73	1.7
Vd	Rock tribe	159	226	51	1.4
VI Finnish Jaalasheep, hand spun, combed					
VIa	Undyed	227	767	34	3.4
VIb	Alder buckthorn	243	733	25	3.0
VIc	Dyer's madder	151	285	37	1.9
VId	Rock tribe	139	389	40	2.8
VII Finnish Jaalasheep, hand spun, carded					
VIIa	Undyed	215	508	22	2.4
VIIb	Alder buckthorn	213	796	30	3.8
VIIc	Dyer's madder	268	248	36	0.9
VIId	Rock tribe	200	305	28	1.5
VIII Finnish Jaalasheep, hand spun, combed					
VIIIa	Undyed	164	822	15	5.0
VIIIb	Alder buckthorn	188	812	15	4.3
VIIIc	Dyer's madder	190	725	14	3.8
IIId	Rock tribe	198	766	25	3.9

As instructed in the textile standard ISO 2062:2009 the *breaking force* is presented in the Table 3 in centiNewtons (cN) with three significant figures. The *Strain* of a yarn at its breaking point is announced in percentages with two significant figures. The *tex value* is expressed with three significant figures and the *tenacity* with two.



## 4.2 Sweat on dyed yarns

The colour fastness to perspiration was evaluated according to the protocol instructed in the textile standard ISO 105-E04: 2008. The tested yarns were compared with the grey scales and the original shades of colours. The results of the acidic test are presented in Table 4 and alkaline in Table 5. The greatest changes in colour were on alder buckthorn and wild rosemary yarns. Staining was scanty in all yarns.

## 5. Discussion

### 5.1 Tenacity of the yarns

In the test presented in textile standard ISO 2062:2009, the hand-spun yarns were found to be stronger than the machine-spun ones. There are several explanations for this phenomenon. One comes from the wool processing: if the fibres lie in a parallel position, that is, if they have been combed, the linear density grows and the yarn is stronger. In the carded wool, the fibres are in disorder and the yarns are weaker. This is easily seen in the tenacity values of the yarns VIa and VIIa, that contain an identical fibre distribution and yarn diameter. The first one has been spun from combed wool and the latter of carded wool; the carded one was found to be weaker.

The fibre distribution was found to be significant to the yarn's strength. The machine-spun yarns contained Semi Fine Finnsheep wool, which achieves the staple length of 4–10 centimetres (Ryder 1983, 524). The Jaalasheep wool contained a primitive kind of wool, that consisted of underwool with a length of c. five centimetres and the outer coat hairs with a length even 20 centimetres. The spinning experiments have proven, that both underwool and long outer coat hairs are needed, in order to spin thin and strong yarns (Andersson and Batzer 1999, 13, 18–19; Andersson 1999, 23–25).

A high degree of twist and plying strengthen the yarns (Seiler-Baldinger 1994, 3). The hand-spun yarn, VIII, which had a spinning angle of 33°, was found to be the strongest. The hand-spun yarns IV, V, VI and VII had a spinning angle of 20°, but nevertheless they were stronger than the machine-spun yarns I and II that had a spinning of angle 30°. With the same spinning angle, the hand-spun and the machine-spun yarns might have had an even greater contrast. Yarn III, despite having been spun from short Finnsheep wool, was strong. It was of combed wool, spun with a spinning angle of 40° and was tightly plied with an angle of 55°. These tricks probably compensated for the shortness of the wool fibres. This yarn had the lowest elongation values that can be explained by a high degree of twist and tight ply.

Table 4. Colour fastness for acidic perspiration (ISO 105-E04: 2008).

No.	Dye plant	Value of staining	Value of colour change	Visual assessment	Change on CIELAB ( $\Delta^*E$ )
1.	Alder buckthorn	4/5	4	more yellowish	8.04
2.	Common tormentil	5	5	no change	2.97
3.	Silver birch	5	5	no change	4.73
4.	Rock tribe	5	4/5	more blue	1.64
5.	Crottle	5	5	no change	2.89
6.	Dyer's madder + Club moss	4/5	5	more intensity	4.24
7.	Dyer's madder	5	5	more intensity	2.45
8.	Northern bedstraw	4/5	4/5	darker	1.81
9.	Common lupine	5	5	no change	9.78
10.	Silver birch	4/5	5	lighter	1.67
11.	Heather	5	5	no change	4.66
12.	Crowberry	5	4/5	more red	8.96
13.	Crowberry	5	4/5	lighter	2.76
14.	Wild rosemary	5	4/5	lighter	9.56
15.	Bog rosemary	5	4/5	colder	5.01

In the past, the yarns were most likely not a result of random selection, but rather intentionally selected from the fittest materials. The weavers of the past probably knew the strength-increasing effect of the long hairs. Indeed, often the yarns from the European Bronze until the Middle Ages contain fibres from both the underwool and the outer coat (Nahlik 1963; Bender-Jørgensen and Walton 1986; Ryder 1978, 1990; Kirjavainen 2005; Rast-Eicher 2008; Brandenburgh 2010). This phenomenon is clearly present in the early medieval textiles found in Greenland. In these finds, the warp yarns, which require a higher tenacity than the weft yarns, have systematically had more hairs than the weft yarns (Walton 2004, 83–87).

### 5.1 Dyeing methods and tenacity

The strongest tested yarns were found to be either undyed or dyed with a fermented alder buckthorn bath. The weakest dyed yarns consistently came from the Dyer's madder bath. The yarns from the alkaline rock tribe bath received values between the other two.

The effect of the dyeing method is most likely connected to the different temperatures of the dye baths as well as the different pH values. Wool as a protein fibre withstands well an acidic environment, but degrades in an alkaline one. However, the test indicated, that dyeing in the alkaline dye bath and especially in cold temperature is not as harmful to the fibre as is often assumed. In fact, the common boiling method of dyeing can be more harmful.

The yarns IVb, Vb, VIb and VIIb, that contained Jaalasheep wool, maintained their strength in an alder buckthorn bath. The yarns IVc, Vc, VIc and VIIc became fragile and sticky when dyed with the Dyer's madder. The greatest loss of strength can be seen in the yarns VIa, VIc, VIIa and VIIb. The alder buckthorn dye and the fermenting in room temperature might be a recommended dyeing method, at least when working with the yarns spun from the double-coated wool. Knowledge of the best fitting dyeing method for different wool types might be important for weavers. For example, when weaving a yarn spun from the primitive kind of wool on a warp-weighted loom (Hoffmann 1964), the warp is highly tensioned and the weak yarns do not stand.

### 5.2 Colour change and staining of the dyes

The test ISO 105-E04: 2008 for the colour fastness confirmed the empiric knowledge of the dyers, i.e., the natural dyes sustain their shades very well. For the industrial dyes, value 4 is adequate and all the studied dyes were found to sustain at least this value, or even better.

The grey scales were found to need a very accurate visual assessment and to be a clumsy tool when assessing particular types of colour changes. Problematic cases appeared, if the yarn became

Table 5. Colour fastness for alkaline perspiration (ISO 105-E04: 2008).

No.	Dye plant	Value of staining	Value of colour change	Visual assessment	Change on CIELAB ( $\Delta^*E$ )
1.	Alder buckthorn	4/5	4	more red	8.15
2.	Common tormentil	5	5	no change	3.72
3.	Silver birch	5	5	no change	3.63
4.	Rock tribe	4/5	4/5	more red	2.33
5.	Crottle	5	5	no change	2.12
6.	Dyer's madder + Club moss	5	4/5	more intensity	5.55
7.	Dyer's madder	4/5	4/5	darker	5.71
8.	Northern bedstraw	4/5	4/5	colder	7.99
9.	Common lupine	5	4/5	more yellow	8.97
10.	Silver birch	4/5	5	lighter	3.49
11.	Heather	5	5	no change	2.39
12.	Crowberry	5	4/5	colder	4.17
13.	Crowberry	5	4/5	lighter	3.97
14.	Wild rosemary	5	4	lighter	10.18
15.	Bog rosemary	5	4/5	brighter	4.39

brighter (Yarn 15, Table 5), darker (Yarn 8, Table 4; Yarn 7, Table 3) more intense (Yarns 13 and 14, Table 4; Yarn 6, Table 5), or the shade of colour preserved the same lightness value, but turned to a different hue (Yarn 4, Table 4; Yarn 4, Table 5).

In general, the grey scale values were in alignment with the CIELAB measurements. For unevenly dyed yarns, the grey scale cards suited better than the CIELAB measurements, because human eyes can define the amount of change from whole yarn at a glance. This probably explains why the common lupine-dyed yarn (Yarn 9, Table 4) was defined as unchanged in visual assessment, but with the CIELAB measurement, this yarn received one of the highest  $\Delta^*E$  values.

The staining of the tested dyes was small. For example, common tormentil, silver birch leaves, heather and lupine-dyed yarns did not stain at all. Because of the good colour fastness properties, it might be difficult or impossible to find any sweat stains from ancient textiles. In addition, if a textile comes from the ground, there might be secondary stains caused by the soil. In certain natural environments, natural dyes can leak out of the fabrics, migrate and stain other fabrics (Ringgaard 2010, 238–240; Bruselius Scharff and Ringgaard 2011).

Nowadays the dyed textiles are expected to last brilliant forever, which can be an acceptable demand of the synthetic dyes, but it is unknown, what was the desired resistance of the dyes in the past. It is possible that the dyes were not meant to sustain over generations. Bright purple rock tribe-dyed yarn fades in two weeks to lilac grey when placed in a sunny window with  $\Delta^*E$  33, but nevertheless this lichen was an important dye source during the 18th century (Cardon 2007, 485–492).

In Finland, turquoise anthocyanin dyes from purple flowers were seen as “good enough” and used despite of the tendency of textiles dyed with them to fade. Moreover, it was possible to re-dye the faded textiles and refresh or change the shades of colours. Blue-giving woad (*Isatis tinctoria*) with good light fastness rarely grows at seashore areas of Finland and was sometimes even cultivated (Linnilä et al. 2002, III/ 63–64). Because of the difficult dyeing method, it was used only by the most skilled dyers. The dyeing with purple flowers was simple and in the agrarian environment the blue flowers were easily available to folk crafts people.

## 6. Conclusions

The empiric experiments made with the eight different yarns were in alignment with what is commonly known about the parameters of yarns: the long fibres, the high degree of twist and the ply increase the strength of a yarn. This data was achieved by testing the yarns that had a close tex value (ISO 1144:1973) with the textile standard (ISO 2062:2009), which measures the breaking resistance.

The tenacity of the yarns was found to be dependent not only on the yarn and wool properties, but also on the dyeing methods. The strongest yarns of this test were found to be either undyed or dyed with alnus buckthorn (*Rhamnus frangula*) and the fermentation method. Most clearly, the effect of the dyeing was found to be present in the yarns that contained both underwool and outer coat hairs. The fermented buckthorn bath produced a red yarn that retained the original strength, or even added it. The selection of the dyeing method might have been important in the past, when the yarns spun from the double-coated wool were woven on the warp-weighted loom.

The yarns that were mordanted and dyed with the boiling method with Dyer’s madder (*Rubia tinctorum*) were quite regularly the weakest ones. The rock tribe (*Lasallia pustulata*) and the fermented urine bath was as harmful to some yarns, but in general this alkaline dyeing method was less degrading to the yarns than one would assume.

In the tests made with the textile standard ISO 105-E04:2008 the natural dyes were found to stand perspiration very well. The traditional Finnish dye plants i.e. the root of common tormentil (*Potentilla erecta*), silver birch bark (*Betula pendula*), crottle (*Parmelia saxatilis*) and heather (*Calluna vulgaris*) did not fade or stain at all. This observation suggests that it could be very difficult

find any sweat stains from prehistoric dyed textiles, especially if the textiles have been dyed with these plants.

Excellent tolerance values for perspiration were also found in the yarns that were dyed with rock tribe and purple lupine flowers (*Lupinus polyphyllus*). These dyes faded soon in direct sunlight and are not favoured by present-day dyers. However, there is historical evidence that tells about the use of rock tribe and purple flowers as sources of dyes. Perhaps the expectations and demands for the permanence of dyes in the colourful textiles have changed during the history. Possibly people did not expect the colours to last forever, but accepted the fading and possibly re-dyed the textiles when needed.

The standardised textile testing methods that are commonly used in the textile industry produced repetitive data that fits well to the experimental textile archaeology. Perhaps we should abandon the term *experimental* and call this kind of study *empiric textile archaeology* based on empiric research methods.

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